Characterizing the Distribution of *Tursiops truncatus* and *Delphinus delphis* along the Mediterranean Coastal Shelf of Israel through Habitat Preference Modeling

Ori Galili

THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE MASTER'S DEGREE

University of Haifa

Faculty of Natural Sciences

Leon H. Charney School of Marine Sciences

Department of Marine Biology

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Supervisors: Prof. Dan Tchernov

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Approved by ______________________ Date 21/11/2021

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Characterizing the Distribution of *Tursiops truncatus* and *Delphinus delphis* along the Mediterranean Coastal Shelf of Israel through Habitat Preference Modeling

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Abstract

Along the Mediterranean coast of Israel, two near-shore dolphin species are prevalent – the common bottlenose dolphin- *Tursiops truncatus* (vulnerable, IUCN) and the common dolphin- *Delphinus delphis* (endangered, IUCN). Both have been observed via ship-board surveys and sporadic sightings, though they differ in distribution - *T. truncatus* is found along the entire coast, and *D. delphis* only in the south. Additionally, researchers in Israel have been surveying the *T. truncatus* population via vessel-based surveys over the last 20 years, while only in the last decade has *D. delphis* become notably present in the south and established a resident population.

The environmental and anthropological factors affecting these species' spatial distribution and determining their habitat preferences in this area, are largely unknown, and understanding them is crucial to any spatial marine planning and conservation measures. This research aims to narrow the knowledge gap by studying habitat preferences for both species, by use of Generalized Additive Models based on observed distributions. As apex predators such as dolphins are key indicators of the health of marine eco-systems, knowledge gained from this study could reflect on the state of the near-shore marine environment in Israel.

Abundance estimates, occurrence maps and habitat preference models were created during this study for both dolphin species. Various explanatory variables were incorporated into the modeling process including depth, slope, distance from shore, sea surface temperature, distance to power or desalination plants, distance to rivers or artificial nutrient sources, presence of artificial structures, type of bottom composition, and survey status (searching / near trawler / near fish cages).

T. truncatus was found to be present in all areas of the continental shelf where survey effort coverage was sufficient. Overall abundance was estimated at 135 ± 15 individuals (± 95% CI) and mean group size was estimated at 5 ± 0.6 (± 95% CI). Sightings near the Haifa Bay and northwards were scarce, though likely in part due to reduced survey effort in that region. Along the rest of the coast, *T. truncatus* occurrence was tied to presence of trawlers across all models, demonstrating a strong anthropogenic influence. Results of habitat preference comparison between seasons in which seawater was hot or cold presented an affinity towards trawlers during the hot season, but not during the cold season, which may be related to energetic budgets or prey availability. Models that neutralized the effect of trawlers predicted the highest probability of dolphin occurrence to be in a corridor parallel to shore, that ranges from 6-10 km from the shore or 40-70 m depth, depending on the model. Even so, it is unclear whether

the preference towards this area is dependent on depth or distance to shore, or possibly other, more complex factors, such as prey distribution or anticipation of trawlers, that may also be influenced by one of former.

D. delphis was observed to be present between Ashdod and Ashkelon, with several anecdotal sightings slightly further north, though the factors driving their limited latitudinal distribution currently remain unknown. Overall abundance was estimated at 37 individuals and mean group size was estimated at 16.2 ± 6.3. Results of habitat preference modeling were limited due to the short time period during which this species was sighted, along with the small spatial area and overall limited number of sightings. Nonetheless, model results presented an affinity of this species to a particular water depth of approximately 30 meters.

This is the first research to study habitat preferences for both *T. truncatus* and *D. delphis* along the Israeli coast and results show a strong anthropogenic influence on the *T. truncatus* population, indicating that this species is sustained in a delicate balance with human activities and that further monitoring is required, in particular fine-scale research focused on feeding strategies and prey preferences.

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1.1 BACKGROUND

"All models are wrong, but some are useful" - statistician George Box

1.1.1 The Importance of Habitat Preference Modeling

Habitat modeling is becoming an increasingly popular tool to study the spatial distribution of a species and its relationship with environmental factors (Bräger et al., 2003; Gilles 2008; Praca et al., 2009; Gilles 2016). Modeling populations' densities, abundance and habitats is advantageous as the models can be used to highlight the main factors that drive a certain species' distribution and also create prediction maps over un-surveyed areas (Cañadas et al., 2005; Druon 2012). Determining driving factors and prediction maps can then guide policy makers in creating the appropriate legislative framework for protection of the species (Gilles et al., 2011; Hammond 2013).

In the field of marine mammal research, habitat models are being applied in many regions worldwide in order to map these cryptic animals' distributions, particularly in areas that are difficult to survey (far offshore) or are heavily impacted by human disturbances (Cañadas et al., 2005; Gilles et al., 2009; Panigada 2017).

In Israel, the last two decades have witnessed considerable anthropogenic intervention in the marine environment- establishing Marine Protected Areas, fishing regulations, conducting of seismic surveys, construction of oil and gas facilities, increase in recreational maritime activities and more. All of these activities affect the marine environment and its inhabitants- marine mammals included (dolphins being most relevant to Israel's coastal waters) (Shaffer 2011; Teschner et al., 2013; https://www.parks.org.il/article/שמורות-טבע-ימיות/).

In addition to legislation and industrial changes, the eastern Mediterranean (and Israel in particular), is experiencing several other types of rapid changes: overfishing (Kaiser et al, 2002; Lewison 2004; Coll, 2010), warming water temperatures (Nykjaer, 2009; Samuel-Rhoads et al., 2013; El-Geziry, 2021) and changes in ecosystem composition. Ecosystem composition has been impacted over the last century by the introduction of invasive species from the Red Sea, entering the Mediterranean via the Suez Canal (Spanier & Galil, 1991; Golani 1998; Goren & Galil, 2005; Zenetos et al., 2005; Rilov & Galil, 2009), and the depletion of local species due to overfishing. This combination of effects drives imbalance across all trophic levels, from primary producers to large predators, and aids the establishment of alien species populations. Anthropogenic climate change is a well described phenomenon with various global effects, and in the eastern Mediterranean it is causing measurable shifts in water temperature (mean of 0.04 - 0.05 degrees Celsius per year) (Samuel-Rhoads et al., 2013; El-Geziry, 2021). Such changes have the potential to alter the spatial and temporal distribution of both the dolphins and their food sources (Wells et al., 2018). The ongoing arrival of invasive species from the Red Sea, both vertebrates and invertebrates, is causing shifts in ecosystem composition of both the benthic and pelagic zones (Rilov

& Galil, 2009). Dolphins are opportunistic predators and can shift their dietary preferences according to available prey (Lewis et al., 2003) but it is unclear how changes in fish and invertebrate communities will affect foraging efficiency and strategies for *Tursiops truncatus* and *Delphinus delphis*.

Dolphins, being apex predators, are key indicators of the health of our marine eco-systems (Azzellino et al., 2014) and changes in their distribution directly reflect changes in the environment, whether the impact is top-down or bottom-up.

1.1.2 Cetaceans in Israel

In the Eastern Mediterranean Sea, only a few studies have been performed on cetacean populations. Although a handful of research cruises have been executed, no long-term ecological research has been conducted, with the exception of the Israeli coast.

In 1998, the NGO ‘Israeli Marine Mammal Research and Assistance Center’ (IMMRAC) began its near-shore monitoring program for coastal dolphins, under the academic umbrella of The Leon Recanati Institute for Maritime studies at the Leon H. Charney School for Marine Sciences, University of Haifa. Today, in addition to IMMRAC, regular monitoring surveys are performed by Delphis (NGO) and researchers from the Morris Kahn Research Station, of the University of Haifa. Based on the data that have been collected regularly in Israel on dolphin populations over the last 20 years, the Mediterranean coastal shelf along Israel’s shoreline was declared an Important Marine Mammal Area (IMMA) by the International Union for Conservation of Nature (IUCN) in 2017 for two dolphin species- *Tursiops truncatus* and *Delphinus delphis* (https://www.marinemammalhabitat.org/portfolio-item/coastal-shelf-waters-southeast-levantine-sea/). These are the two species sighted routinely along the shallow continental shelf of Israel, and they are the focus of this research.

A B

Image 1. Schematic illustrations (not to scale) of A) *Tursiops truncatus* and B) *Delphinus delphis*

1.1.3 The Marine Habitat of Israel (Mediterranean Sea)

The Mediterranean coastline of Israel is 196 km long, runs north to south, and is virtually featureless, with no significant estuarine rivers. The southern region is characterized by fine sand while the north by coarser sand and large rock formations (Zviely et al., 2007). The slope is gradual, and in the south, the edge of the continental shelf (~100 meters depth) can be reached at a distance of approximately 20 km from shore, while in the north the shelf is narrower, approximately 10 km wide (Maritime Space Policy -מסמך מדיניות למרחב הימי של ישראל). Seawater temperature has a wide annual variation, with sea surface temperature ranging from 16°C in the winter, to 30°C in the summer (Copernicus Marine Service Information website), and prevalent currents run from south to north, as part of the counterclockwise circulation of the Mediterranean Sea (Hamad et al., 2006). The eastern Mediterranean Sea is ultra-oligotrophic and in the Levantine basin near Israel, the main sources of nutrients include sewage treatment plants, industrial discharge, rivers, the Nile River delta, and occasionally Saharan dust formed by aeolian processes (Thingstad et al., 2005; Suari et al., 2015). However, satellite data reveal elevated concentrations of chlorophyll *a* in the vicinity of the Nile River delta extending as far north as the Gaza strip (D'Ortenzio et al., 2009; Suari et al., 2015).

1.1.4 *Tursiops truncatus* Habitat Preferences

T. truncatus is widely distributed in all oceans, from cold temperature to tropical waters and in semi-enclosed seas. Two ecotypes exist, one coastal and the other oceanic, with different morphological and ecological characteristics (Jefferson et al, 2015). According to the IUCN, the conservation status of its Mediterranean subpopulation is 'Vulnerable' (https://www.iucnredlist.org/species/16369383/16369386)

Formerly common all over the continental shelf of the Mediterranean, the distribution of *T. truncatus* is now fragmented into smaller units, probably due to anthropogenic degradation of its habitats (Bearzi, Fortuna, & Reeves, 2009). It is found mostly in coastal waters and occasionally offshore near the continental slope. The latter may represent the deep-water ecotype, but this assumption awaits genetic/morphological proof. In the Mediterranean, it lives in groups usually smaller than 20 individuals, although greater aggregations have been observed. It is present along the entire Israeli coast, from Rosh-HaNikra in the north down to the Gaza border in the south, mainly shallower than 100 m (Scheinin et al. 2014), with a mean group size of 4.9 ± 0.5 according to Scheinin et al. (2014) and 4 ± 0.2 according to Zuriel (2014).

T. truncatus are regarded as a cosmopolitan species, with flexible foraging strategies and dietary preferences varying from region to region (Reynolds et al., 2000; Dos Santos et al., 2007; Borrell et al., 2021). In Israel, results of stomach content analysis show that the most commonly consumed fish species are the Balearic eel (*Ariosoma balearicum*), Bogue seabream (*Boops boops*), and Striped seabream (*Lithognathus mormyrus*). The prevalence of these species in *T. truncatus* stomachs is also attributed to local trawl fisheries, that the dolphins follow and utilize as a foraging strategy by feeding directly from the net, feeding on demersal fish disturbed by the net, and feeding from fish discarded from the vessel during the catch sorting process. *Ariosoma balearicum* is a sand burrower with no commercial value, typically disturbed by trawlers and discarded from the catch, while seabreams are fish of commercial value (Scheinin et al., 2014).

Throughout the Mediterranean, habitat modeling has been evaluated in for *T. truncatus* in various regions. In the northern Adriatic Sea, findings have shown that dolphin occurrence increased in deeper waters, away from the coast, and in the vicinity of trawlers while occurrence decreased in the vicinity of recreational fishing vessels and mussel farms (Bonizzoni et al., 2021). In the Gulf of Corinth, Greece, modeling results show that *T. truncatus* display a preference towards continental shelf waters and fish farms (Bonizzoni et al., 2019), while across the nearshore waters of Spain, depth had the most effect on this species distribution, and in some section also sea surface temperature (Cañadas et al., 2005, Cañadas & Hammond, 2006). In the Gulf of Taranto, the most northern section of the Ionian Sea, *T. truncatus* were found to have increased occurrence in the vicinity of fishing areas, and decreased occurrence in the vicinity of industrialized areas, as well as a general preference towards depth correlating with the continental shelf (Carlucci et al., 2016).

1.1.4 *Delphinus delphis* Habitat Preferences

D. delphis is globally an oceanic species, widely distributed in tropical to colder waters of the Atlantic and the Pacific, with no proof of its occurrence in the Indian Ocean, other than southwest Australia (Jefferson et al, 2015). In the Mediterranean Sea, it used to be one of the most common species, found in both oceanic and neritic environments, but has since experienced a substantial reduction in geographic range and numbers (Bearzi, 2003; Bearzi & Genov, 2021). *D. delphis* are regularly observed near the Straights of Gibraltar, and the Alboran Sea, though their density is notably lower in other parts of the western Mediterranean, including the Adriatic Sea. Low densities were observed throughout most of the eastern Mediterranean, with the exception of the Aegean Sea, and a small local off the southern coast of Israel. The southern region of the eastern Mediterranean is lacking in data and therefore the status of this species is unknown in that region. *D. delphis* in various regions of the Mediterranean are regularly sighted in mixed species groups, along with *Stenella coeruleoalba,* with which they also cross breed, as is evident by the documentation of hybrid individuals (Notarbartolo di Sciara & Birkun, 2010; Vella et al., 2020; Bearzi & Genov, 2021; Bearzi et al., 2021). *D. delphis'* foraging behavior and daily activity cycle may be habitat-specific (Henderson et al., 2012). The sub-population of *D. delphis* in the Mediterranean Sea is categorized as 'Threatened' by the IUCN (www.iucnredlist.org; Bearzi 2017).

In Israel, *D. delphis* are sighted regularly in recent years, all year round and mostly south of Ashdod in large groups (15-30 individuals), including calves (Kerem et al, 2014). To date, all reported *D. delphis* sightings in the area were in shallow water, in depths less than 40m (IMMRAC unpublished data). However, due to low survey effort in deep water in the area, and the fact that *D. delphis* tends to inhabit deeper water than *T. truncatus* in overlapped area around the world and in the Mediterranean Sea in particular (Bearzi et al., 2003; Bearzi et al, 2005; Cañadas & Hammond, 2008), it is reasonable to assume that there may be some pelagic presence of *D. delphis* in Israel as well. Lastly, it should be noted that nearly all surveys in this region were conducted during the day, with the vast majority of surveys setting out in the morning and ending by noon, therefore it is also possible that *D. delphis* spatial distribution is also affected by diurnal patterns overlooked by the data. Small delphinids, including *D. delphis* have been documented to exhibit changes in behavior and distribution (nearshore vs offshore waters) across various studies (Garaffo et al., 2007; Henderson et al., 2012; Tyne et al., 2015).

D. delphis are typically regarded as opportunistic feeders, foraging mainly on small pelagic fish, with their main target species in the Mediterranean consisting of European anchovy (*Engraulis encrasicolus*) European sardine (*Sardina pilchardus*), round sardinella (*Sardinella aurita*), and garpike (*Belone*

belone) (Bearzi et al., 2003; Vella et al., 2020). However, in Israel, results of stomach content analysis from five sub-adults revealed the most common prey species to be the Balearic eel (*Ariosoma balearicum*), a sand burrower, which is one of the primary prey of *T. truncatus* in the same area (Brand et al., 2019).

1.1.5 Population Size (Abundance) Estimates

Estimation of abundance is a basic ecological tool for assessing the state of a population. Comparison of abundance estimates over time enables monitoring of trends in a population, thus guiding decision making for conservation purposes (Verdade et al., 2014). Various studies across the Mediterranean and world-wide have estimated abundances of localized dolphin population in order to set baselines (Hammond et al., 2002; de Segura et al., 2006; Hammond et al., 2013), examine seasonal variation (Fortney et al., 1998; Irwin et al., 2004), compare between populations in different ecosystems (Balance et al., 1998), and inform management and conservation efforts (Mullin et al., 2004; Dick et al., 2011; Durden et al, 2011). The three most established methods of abundance estimation are based on either line-transects, models (see Methods 2.2) or mark recapture methods. Estimates based on modifications of both line transect and modeling methods were attempted and compared during this study for the near-shore dolphin populations in Israel.

1.1.6 Occurrence Maps

One of the fundamental principles in ecology and conservation is defining species' extent of occurrence and distribution (Bonizzoni et al. 2019; Heinrich et al., 2019). Geo-plotting of the observed sightings of both *T. truncatus* and *D. delphis* aids in visualizing the extent of their occurrence and determining the regions of the study area which they frequent. However, maps of observed occurrence only loosely correlate to species' abundance and preferred habitat, as they are prone to bias due to sample size, imperfect detections or uneven survey coverage (He et al., 2000; Dorazio et al., 2006). Therefore, in this study, several modifications and statistical tests have been utilized to partially counter the bias created by uneven survey coverage across the study area.

1.1.7 Knowledge Gaps

Marine mammal surveys have been inconsistent across the Mediterranean Sea, both temporally and spatially (Mannocci et al., 2018), with the southern and eastern portions of the Mediterranean most lacking in data. Mannocci et al. (2018) further found that for basin-wide habitat modeling, significant extrapolation would be required in the eastern Mediterranean, thereby producing unreliable results. Additionally, in the Levantine Basin, where there is a general knowledge gap regarding distribution and abundance of cetaceans (Kerem et al., 2012; Dede et al., 2015), Israel is the only country conducting long term ecological cetacean research. Though the coastal dolphin populations have been surveyed regularly in Israel over the last 20 years, no habitat modeling work has been done for this area so far.

The most recent thorough analysis of the Israeli dolphin population was performed in 2010 as a part of a PhD thesis (Scheinin 2010). The estimated abundance of *T. truncatus* was 360 individuals, though the methodology used was not congruous with established abundance estimation methods (i.e. distance sampling), and therefore may present an over-estimation due to attraction of the dolphins to the surveying vessel and bias towards surveying near bottom trawlers which attract the dolphins. The mean group size was estimated as 5.7, and mean encounter rate was 1.13 groups per 100 km of effort (Scheinin, 2010). Scheinin (2010) also concluded that approximately 50% of the observed activity budget of *T. truncatus* was foraging behavior (surface feeding / deep (probably benthic) foraging / foraging in association with trawler), which may be indicative of a population that spends much time and effort feeding, possibly due to scarce food sources.

A general assessment for *D. delphis* was not made at that time, as its population was not consistently/predictably present in the study area during the years preceding this PhD research.

Since 2010, several other aspects of the dolphin populations in the eastern Mediterranean have been studied such as genetic differentiation/isolation (Gaspari et al., 2015), relationship with trawlers (Scheinin 2010; Scheinin et al., 2014), stranding events, stomach contents (Bearzi et al, 2005; Brand et al., 2019), and detection by means of acoustics. However, most of these projects have focused on *T. truncatus* alone and none have focused on the environmental variables affecting both *T. truncatus* and *D. delphis*, by defining the limits of their habitat and the environmental factors driving their distribution. This study aims to gain insight to the main drivers of *T. truncatus* and *D. delphis* distribution in the near-shore Israeli shelf waters.

1.2 OBJECTIVES AND RESEARCH QUESTIONS

Research objectives

The main aim of this research is to try to determine the environmental variables driving the distributions of the two coastal dolphin species.

This will be achieved by 2 main objectives:

1. Defining the distribution of the two coastal dolphin species along Israel's Mediterranean coast and identifying the boundaries of their habitats over space and time.
2. Determining the environmental variables, both natural and anthropogenic, that affect each of the dolphins' habitat boundaries by acting as either attracting or deterring factors. This second objective is of particular significance due to worldwide climate change. Locally, the effects of climate change are especially noticeable in the rapidly warming waters of the eastern Mediterranean (Nykjaer, 2009).

Significance of the Study

These objectives will assist in providing guidelines for implementing conservation measures, e.g., by establishing Marine Protected Areas (MPAs), areas that are restricted in terms of industrial development or areas that are limited for oil and gas exploration. MPAs and fishing restrictions are paramount for the near shore dolphin populations in Israel, as entanglements in fishing gear is a major cause of mortality for *T. truncatus* and in several cases also *D. delphis* (IMMRAC and Delphis unpublished data). The current MPAs are quite small in size, and highly segregated. In the last decade, Israel has seen much industrialization of its marine territories following oil and gas explorations, the construction of two new ports (in Haifa and Ashdod) and more (Technion, 2015), with no limitations relating to the local dolphin population. Today there are many stakeholders planning to utilize the marine territorial waters, and due to this, passing legislation and approving new MPAs requires strong scientific evidence, showing the efficiency and necessity of such areas.

By determining the spatial distribution of the two coastal dolphin species in Israel, along with the environmental variables driving them, this research will contribute to demonstrating the necessity of protecting specified marine regions.

Working hypothesis

As the Levantine basin is known to be highly oligotrophic and overfished (McCall 2008), the two hypotheses for this project are:

1. The drivers influencing the distribution patterns of the two dolphin species are environmental factors that determine prey (fish) habitat (Baumgartner et al. 2001) such as depth, water temperature, sediment type and productivity (with chlorophyll *a* as a proxy).
2. Dolphin occurrence will likely be associated with trawlers as they aggregate fish in their nets and provide a dense “source” of prey in the barren marine environment (Scheinin 2014).

2.1 STUDY DATASET

2.1.1 Database Construction

The study area chosen for this research was the continental shelf stretching along the Mediterranean coastline of Israel. This area includes the majority of survey effort, and the majority of sightings for both coastal dolphin species of interest. The study area's boundaries were defined by the coastline (to the east), international borders (to the north and south) and the 200 m isobar (to the west). However, the deep waters of the Achziv Canyon in the north (Sade, 2006), are as near to the shore as most sections of the continental shelf and were a significant part of the long-term monitoring, therefore, a section of the Achziv Canyon was included into the study area, although its depth surpassed 500 m.

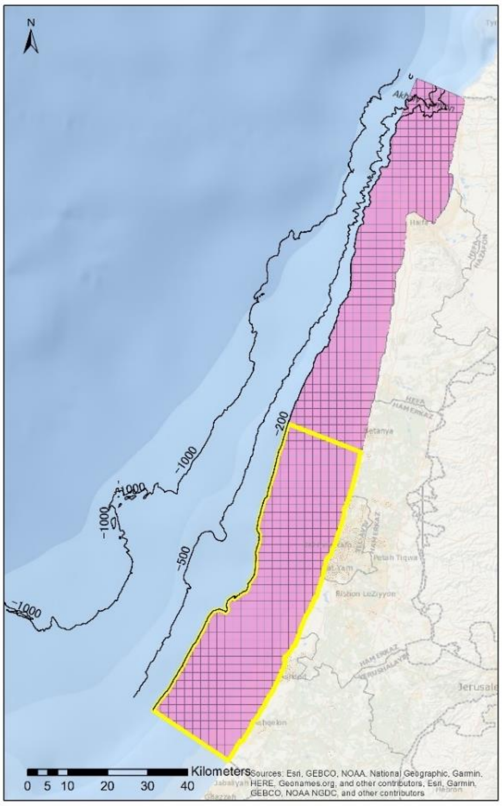


Figure 1. A 2 x 2 km gridded map of the study area. Section outlined in yellow indicates the ‘Dd Area’ in the south. Also displayed are the 200 m, 500 m and 1000 m isobars.

The study area was divided into 2 x 2 km grid-cells, in order to create a high-resolution dataset that differentiates between depths, substrates and can define proximity to various attributes in the marine environment. Figure 1 shows the gridded map of the study area, on which the 200 m, 500 m and 1000 m isobars are marked. A sub-section of the data set was utilized during various phases of the study relating to *D. delphis*, because this species’ extent of occurrence does not span across the entire study area. For this reason, the southern portion of the study area, which includes all *D. delphis* sightings, has been designated to an area that will be referred to from here on as the ‘Dd Area’ (Figure 1).

A data point in the dataset was constructed for each occasion when the survey vessel passed within a grid-cell.

Each data point was then associated with:

- General survey status (searching / dolphin sighting)
- Search type (unconditional search, search near trawler, search near fish cages, search near power plant, vessel type)
- Beaufort Sea State (0, 1, 2, 3, 4, 5)
- Dolphin sighting parameters, if sighting occurred (number of individuals, behavior)
- Environmental parameters (detailed in **Sections 2.1.3, 2.1.4**)

2.1.2 Data – Dolphin Occurrence

Over the last 20 years, IMMRAC, Delphis, and Morris Kahn Marine Research Station, University of Haifa researchers have been conducting nearshore shipboard surveys in order to study the coastal dolphin population. During these surveys, dolphins are the target species and information on species, pod size, behavior and presence of calves / juveniles are recorded. The ship's track is continuously recorded, as well as the sea conditions (wind, wave height, Beaufort Sea State). Sightings of other species of megafauna such as birds, turtles and fish as well as marine debris are also collected. Although the data input platform has changed three times between hand-written notes, including a designated tablet program and a designated phone app (Marco, 2017), the core information collected, and the surveying methodology have remained consistent. An example of vessel tracks along with dolphin focal follows recorded from surveys conducted during 2018 can be seen in Figure 2.

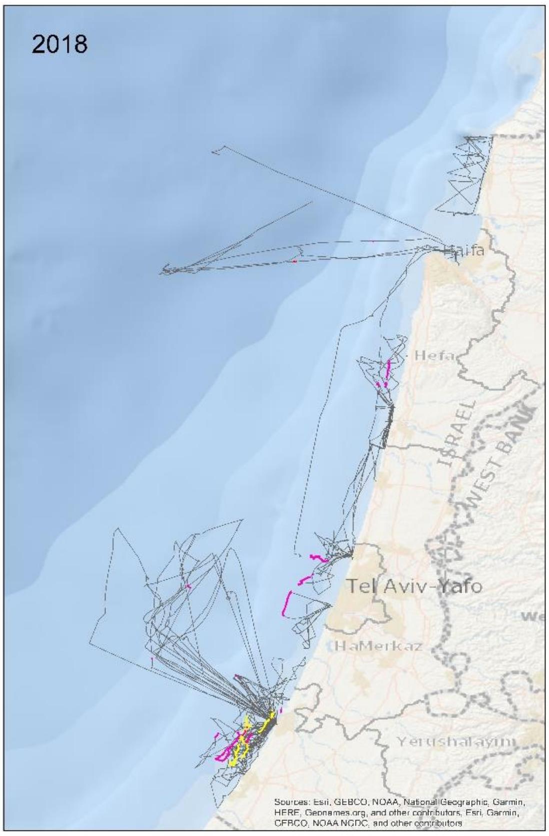


Figure 2. A representative map displaying the ship-board survey work performed in 2018. Survey tracks displayed in grey, *Tursiops truncatus* sightings in pink and *Delphinus delphis* sightings in yellow.

According to the surveying methodology, surveys should be initiated only when sea conditions are expected to at Beaufort Sea State 2 or below, include at least one designated surveyor/observer, and should be conducted on either a RIB craft (rigid inflatable boat) or a sailboat, with boat speed between 7-12 knots. The vessel's course should run in a zig-zag pattern to the north or south of its port between depths of 20-60 meters, though if a trawler is present in the within reachable distance, the vessel leaves its planned course in order to search for dolphins feeding around the net. When a dolphin sighting occurs, the survey vessel follows the pod as long as possible in order to take photos for individual identification and to record behavioral information. Surveys are typically conducted in the morning when sea conditions are the calmest, for a duration of 4-6 hours. As surveys were often performed upon available platforms of opportunity, effort was not spread out evenly across the entire study area, and methodology was not always adhered to. Figure 3A displays a map of the accumulated ship track lengths (effort), totaled across all 2*2 km grid-cells in the study area during the period of 1999-2020, highlighting the bias created toward certain areas of the Israeli coast. Figure 3B similarly displays the dolphin sightings collated in the study area during the same time period.

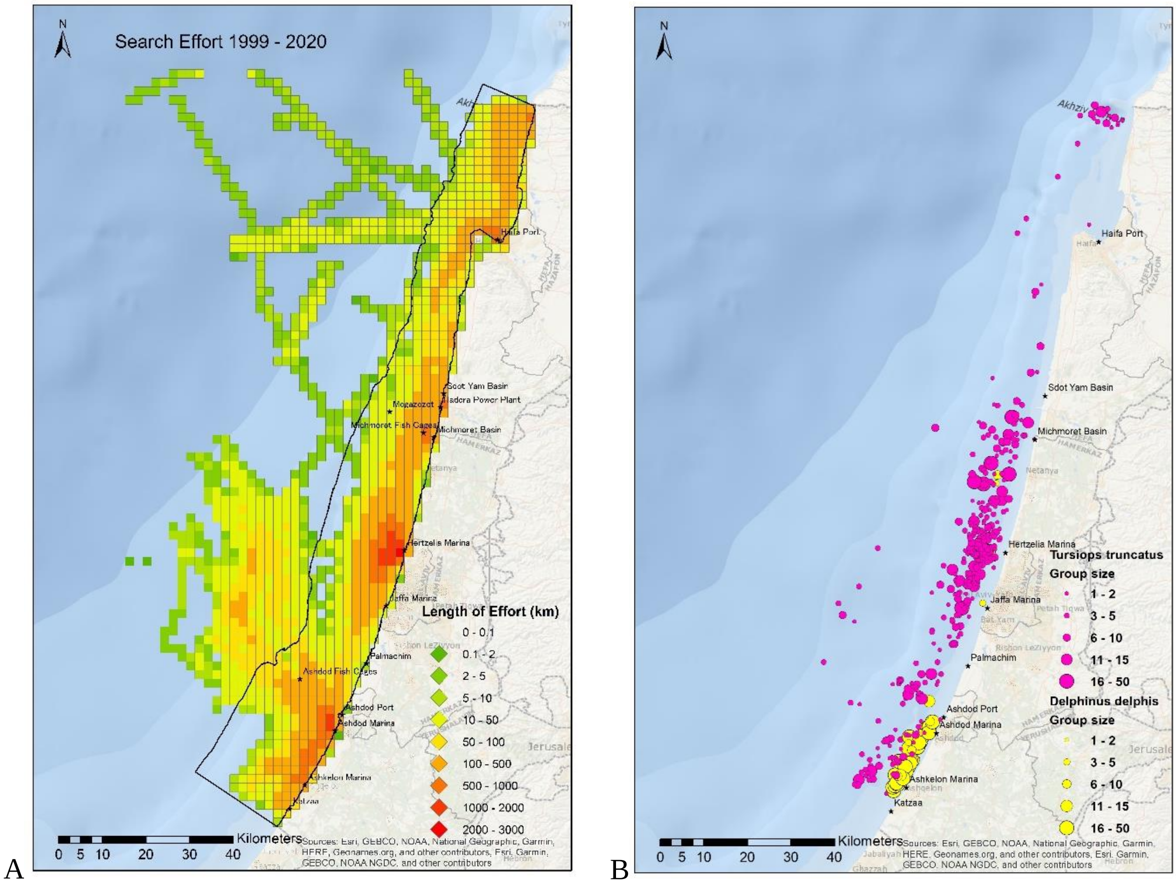


Figure 3. A) Totaled survey track lengths (km) per 2 x 2 km grid cell, over the years 1999-2020. B) *Tursiops truncatus* (pink) and *Delphinus delphis* (yellow) sightings over the years 1999-2020. Larger circles represent larger group sizes (see legend).

Between the years 1998 to 2020, 1137 ship-board surveys covered a total of 45,384 km and recorded 346 dolphin sightings; 306 *T. truncatus* sightings (group sizes: 1-50, mean group size ± 95% CI: 5 ± 0.6) and 40 *D. delphis* sightings (group sizes: 4-30, mean group size ± 95% CI: 16.2 ± 5.1). Surveys were carried out year round, with totaled-surveys-per-year ranging between 6-170, and totaled-sightings-per-year ranging between 2-45. Overall, survey effort increased across the years, as can be seen in Figure 4A, while number of sightings has been variable (Figure 4B).

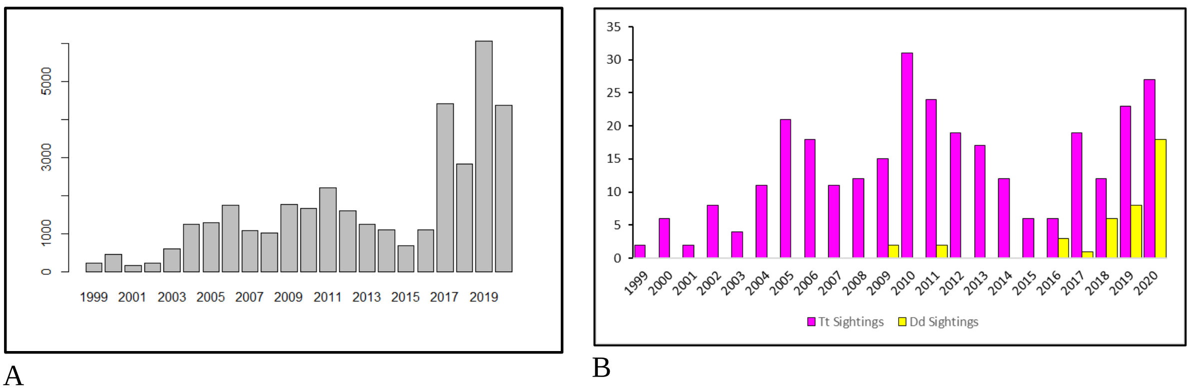


Figure 4. A) Total length of survey effort (km) per year. B) Number of *Tursiops truncatus* (pink) and *Delphinus delphis* (yellow) sightings per year.

In order to fill in the gaps, regarding areas of the coastline where dolphins were rarely sighted during designated surveys, data from the public was used to record sightings reported by boaters, fisherman, kayakers, swimmers, etc. Although this data has been collected since 1999, only data from the years 2015-2019 have been mapped, as can be seen in Figure 5. These sighting reports were used for mapping only, and with the information being 'presence-only' data, were not used for habitat modelling.

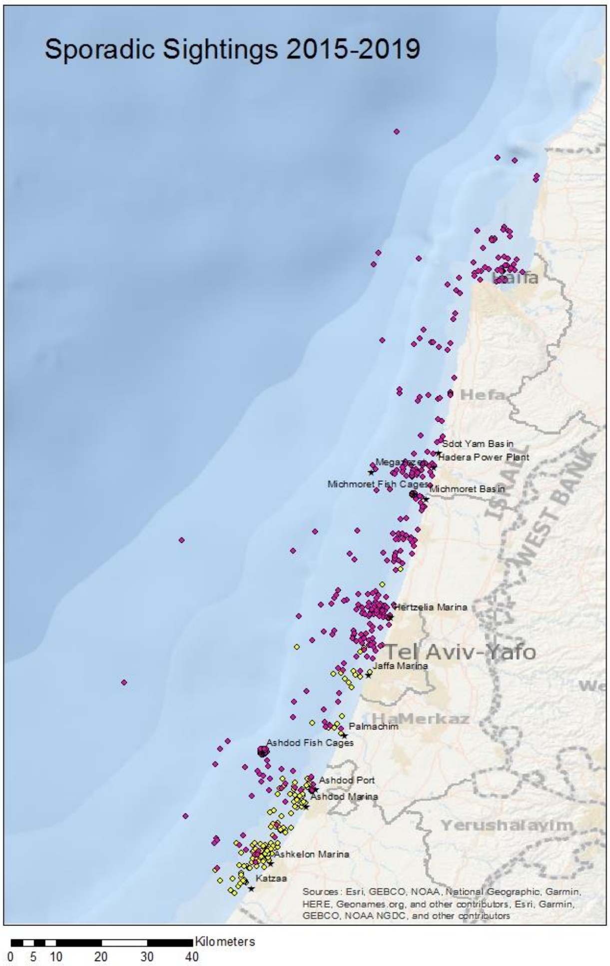


Figure 5. *Tursiops truncatus* (pink) and *Delphinus delphis* (yellow) sighting, reported by the general public, between the years 2015-2019.

2.1.3 Data - Environmental

For this research, a large array of environmental data was gathered from multiple sources.

Depth- obtained from GEBCO Compilation Group (2020), displayed and processed in ArcGIS. Various iterations of the depth parameter (per grid-cell) were obtained from this dataset, such as mean depth, minimum depth, maximum depth and depth at the center-point. Ultimately, 'mean depth' was the parameter chosen for the modeling process.

Slope- obtained from GEBCO Compilation Group (2020), displayed and processed in ArcGIS. Various iterations of the slope parameter (per grid-cell) were obtained from this dataset, such as mean slope, minimum slope, maximum slope and slope at the center-point. Ultimately, 'log(mean slope)' was the parameter chosen for the modeling process.

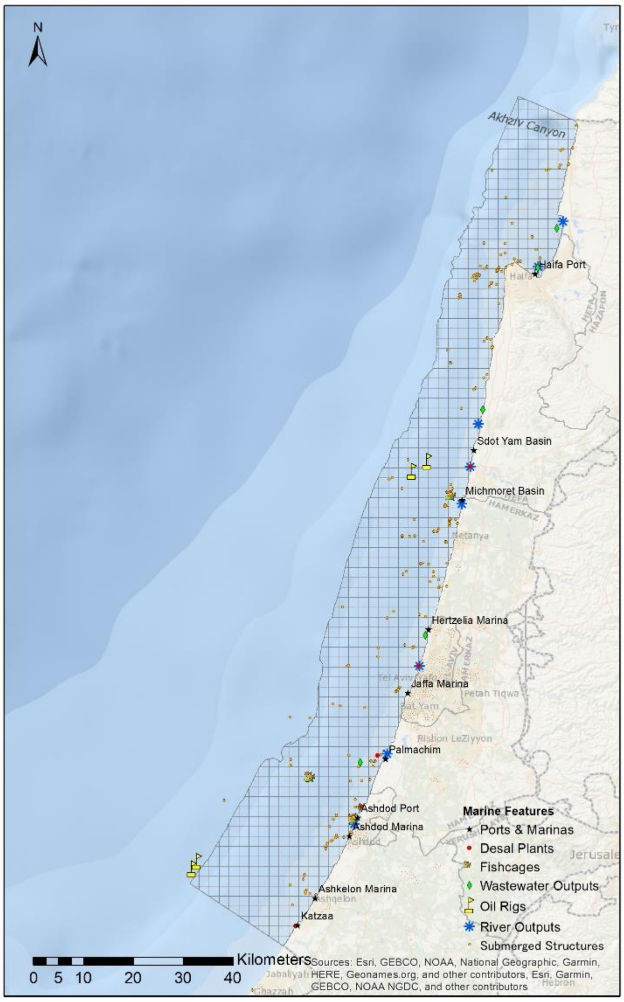


Figure 6. Marine features across the study area, relevant to this research.

Distance from Shore- mapping and distance measurements performed in ArcGIS, based on country border shapefiles from DIVA-GIS website.

Distance to Rivers- mapping and distance measurements performed in ArcGIS, based on river delta locations as displayed in World Oceans Basemap (2014). Rivers referenced in this dataset are based on IOLR Monitoring Reports (IOLR 2015, 2016, 2017, 2018) found in the Ministry of Environmental Protection website (https://www.gov.il/he/departments/topics/seas_and_coasts), that monitor nutrient and pollution outflow from the various rivers along Israel's coast (Figure 6).

Distance to Artificial Nutrient Sources- mapping and distance measurements performed in ArcGIS, based on pipelines permitted to release organic waste into the marine environment according to the Ministry of Environmental Protection website (Figure 6).

Distance to Power & Desalination Plants- mapping and distance measurements performed in ArcGIS, based on pipelines permitted to release brine or coolant water into the marine environment according to the Ministry of Environmental Protection website (in the past, the website contained a map of pipeline locations) (Figure 6).

Artificial Submerged Structures- locations of artificial submerged structures such as shipwrecks and other unidentified wreckage was obtained from local fishermen and divers (Figure 6).

Rigs and Fishcages- include the known locations of the Tamar, Mari-B and Leviathan rig, as well as the Ashdod and Michkmoret offshore fish cages (Figure 6).

Bottom Content- type of bottom content (sand / mud / rock) was obtained thanks to the assistance of the Geological Survey of Israel (Almogi-Labin et al., 2012; Elyashiv et al., 2014a; Elyashiv et al., 2014b; Tom et al., 2015a; Tom et al., 2015b)

2.1.4 Data – Remote sensing

Two parameters of environmental data were obtained from remote sensing- sea surface temperature and chlorophyll *a* (as a proxy for primary production), both obtained via the E.U. Copernicus Marine Service Information website. When applying data derived from satellites, several concerns arise. The first concern regards the spatial resolution of the dataset, which should match the resolution of the study's dataset, and the second concern regards missing data from occasions when it is not possible to obtain measurements, such as obscuring cloud layers.

When considering sea surface temperature across the study area, the majority of the variability across this parameter occurs over time (between days), and not over space. On this basis, it is reasonable to extrapolate sea surface temperature values across the entire study area given a neighboring measurement during a certain day, and therefore a data model was used that provided daily means.

Sea Surface Temperature (°C) - Obtained from the model 'MEDSEA_REANALYSIS_PHYS_006_004' (Mediterranean Sea Physics Reanalysis). Spatial resolution 0.042 x 0.042 degrees.

When considering 'chlorophyll *a*' measurements, it is important to recognize that the eastern Mediterranean Sea and Levant Basin in particular is considered to be ultra-oligotrophic (Krom et al., 2004), and values are typically low (Siokou-Frangou et al., 2010). In addition, 'chlorophyll *a*' and primary production are not distributed uniformly across the study area and are affected by currents, upwelling, downwelling, localized nutrient sources, depth within the water, stratification and more (Siokou-Frangou et al., 2010). For this reason, it would be preferrable to use direct measurements as opposed to models, in order to guarantee the association of the measured value to the actual point of interest, both spatially and temporally. However, when obtaining measurements from the 'OCEANCOLOUR_MED_CHL_L3_NRT_OBSERVATIONS_009_040' dataset, many measurements were missing, likely due to cloud cover. An attempt was made to create larger cover for the data set by averaging the values measured in each point over a three-day period, but even this artificial extension of the data resulted in coverage of only 42% of the dataset.

In a final attempt to utilize 'chlorophyll *a*' in this study, data was obtained from a data model, available in the Copernicus website. The extrapolation method used in this dataset is complex, and relies on multiple other datasets, making it hard to predict the accuracy and errors of this dataset. Detailed information on the measurements and models that are utilized can be found on the Copernicus website (https://resources.marine.copernicus.eu/product-detail/MEDSEA_MULTIYEAR_BGC_006_008/INFORMATION).

The use of a data model improved coverage of ‘chlorophyll *a*’ data to a match 88% of the entire *T. truncatus* dataset. The missing 12% stemmed from areas close to shore which are prone to high variability, resulting in unreliable extrapolation predictions, and are therefore not included in the ‘chlorophyll *a*’ data model. Within the nearshore grid-cells, where chlorophyll values were unavailable, 35 *T. truncatus* sightings occurred. Therefore, the consequence of incorporating chlorophyll into the modeling process is the loss of 11% of all *T. truncatus* sightings in the model.

Due to the methodical flight paths and measurement intervals of the satellites, which do not fully align with the shape of the coastline, the nearshore areas in which remote sensing data was unavailable varied across different sections of the coast. While some of the nearshore grid-cells did contain an estimated chlorophyll value from the data-model (due to proximity to an actual measurement point), others did not, thus creating a corridor of lacking data, up to 3 km wide in some sections, running parallel to the coast. It should also be noted that satellites measure ‘chlorophyll *a*’ *surface* concentrations, which are known to be extremely low in the Levant Basin, while the highest concentrations are found around the ‘Deep Chlorophyll Maximum’, which is typically found at a depth of 80-110 meters in this region (Yacobi et al., 1995; Suari et al.,2015).

The vast majority of *D. delphis* sightings, occurred close to shore, at distances between 2-4 km from the coast, making it difficult to reliably match the survey area and sightings with satellite derived ‘chlorophyll *a*’ data. Additionally, the *D. delphis* dataset includes all survey effort and sightings from the year 2020, and at the time this study was performed, modeled ‘chlorophyll *a*’ data was not yet available for the year 2020.

*’OCEANCOLOUR_MED_CHL_L3_NRT_OBSERVATIONS_009_040’ = Mediterranean Sea Surface Chlorophyll Concentration from Multi Satellite and Sentinel-3 OLCI Observations.

*’MEDSEA_MULTIYEAR_BGC_006_008’ = Mediterranean Sea Bio-geo-chemistry Reanalysis Model. Chlorophyll *a* (mg/m^3), Spatial resolution 0.042 x 0.042 degrees.

2.2 POPULATION SIZE ESTMATION

2.2.1 Estimation Based on Concepts from Distance Sampling

Population size for both *T. truncatus* and *D. delphis* were estimated by use of a modified method, with principles based on distance sampling (Buckland et al., 2015). Initially, density of sightings was estimated by counting the number of sightings along a survey section and multiplying the length of the section by the "width" of the transect, in order to calculate an area for which the sightings occurred rather than a 1-dimensional line. For estimation of overall population density, as opposed to density of sightings, this value was then multiplied by the average group size. The density results were then assumed to be uniform across the study area, and therefor applied across the entire space for an estimation of the total abundance. For estimation of density and abundance of *D. delphis*, only the 'Dd Area' (See Chapter 2.1.1) survey effort and sightings were utilized.

Two main issues arise from this estimation method, the first relates to the assumption that the dolphins are uniformly dispersed across the study area, which is likely not the case, and the second relates to the "width" determined for the surveys. The varying spatial distribution of the dolphins could be countered by applying a survey pattern that provides even coverage across the majority of the survey area, though this was not executed throughout the surveys in Israel, thereby creating an inherent bias in this estimation. The "width" of the transect could be defined by the average distance of sightings from the vessel, or the maximum distance of sighting from the vessel, neither of which accurately capture the actual distance from the boat that is covered during the survey. In order to best define the "width" of the transect, the concept 'Effective Strip Width' (ESW) was borrowed from distance sampling, which refers to the distance from the vessel for which it is assumed that **all** individual that were present **-** were sighted.

According to distance sampling methodology, the parameter ESW is to be calculated separately for each survey based on survey results (number of individuals sighted from the vessel at various distances), however, since this distance was not documented with precision during the surveys performed in Israel, this parameter had to be estimated in a different manner. ESW if affected by a multitude of factors, the most important of which are 'observation deck height', 'sea state' and 'species' (as they display different behaviors and visibility). According to Barlow and Gerrodette (1996) ESWs for observing 'Large Delphinids' (*T. truncatus*) and 'Small Delphinids' (*D. delphis*) from a vessel with an observation deck 10 meters above sea level are 1.1 and 0.58 km respectively. The surveys caried out by Barlow and Gerrodette (1996) were conducted in sea-states of Beaufort 5 or less, while those in Israel were conducted in 3 or less, with a few anecdotal surveys conducted in sea-states 4 or 5.

To estimate the ESWs throughout the surveys conducted in Israel, data was divided into several categories according to survey vessel type, and the average deck height for each vessel type was established. Following the measurements from Barlow and Gerrodette (1996), each categorical vessel type was assigned an ESW according to the proportion between average deck height of the categorical survey vessel, and the 10-meter-high research vessel from the paper.

2.2.1 Model Based Estimation

Population size can also be estimated via spatial modeling. This process is done by fitting a spatial model based on a distribution that utilizes count data and the best-fitting environmental predictors (variables). The model is then able to establish a prediction of the number of individuals for a given grid-cell based on the values of the environmental variables relating to that grid-cell. A prediction grid is separately prepared for the entire study area, and each cell is assigned the appropriate values for all environmental variables included in the model. The model is then requested to predict number of individuals for all cells of the prediction grid, and these are then averaged to construct an overall estimate (Peel et al. 2013). Model-based abundance estimates were also produced from several models in this work and compared to distance-sampling-based abundance estimates.

2.3 OCCURANCE MAPS

The creation of occurrence maps was a stepping-stone in the process of habitat preference modeling. These maps display the distribution of the dolphins' occurrence, based on geographic locations, regardless of environmental variables or any additional speculations. Due to the uneven surveying effort across the study area, two methods were used to create occurrence maps that countered this bias: modelled maps and maps from non-correlated data only.

2.3.1 Modelled Occurrence Maps

Modelled occurrence maps were created using the same GAM models utilized for studying habitat preferences. The only explanatory variables included in the 'occurrence map' models were coordinates of the sightings and survey effort. Models were created separately for *T. truncatus* and *D. delphis*, and predictions were plotted using ArcGIS.

2.3.2 Non-Correlated Data – Occurrence Maps

One of the main concerns when constructing occurrence maps is normalizing the number of sightings to the amount of survey effort (measured in km) in the vicinity of the sighting. It is not enough to divide the number of sightings by the number of km searched, but rather, a method is needed to discriminate areas where extreme amounts of survey effort, both high and low, create a bias in the number of sightings. The method utilized for this discrimination is a statistical test - Spearman's Rank Order Correlation Test.

In order to utilize Spearman's Test – correlation was tested between the number of sightings within a grid-cell, and the total distance (km) of survey effort in the same grid-cell, with values paired for each grid-cell across the entire study area. A step-wise process was conducted, during which removal of data from grid-cells with the lowest total distance of survey effort took place, until correlation was non-significant ($p > 0.05$). This threshold was then considered the minimum amount of survey effort required to determine the presence, absence, and encounter rate of a species in a given area. This subset of the survey data will be referred to as 'non-correlated' data throughout the rest of this work.

2.4 HABITAT MODELING

As described in Chapter 2.1, both the dolphin occurrence data and the environmental data was plotted across the study area using ArcGIS across a 2 x 2 km grid. This dataset was then analyzed using GAMs (Hastie and Tibshirani 1990; Barry et al., 2002; Cañadas et al., 2008; Gilles et al., 2009; Proelss et al., 2011; Dähne et al., 2013; Panigada et al., 2017), to evaluate the relationship between the response (dolphin occurrence) and the explanatory (or predictor) variables to predict the habitat use of dolphins. GAMs are well suited to model nonlinear relationships between cetaceans and habitat covariates (Gilles et al. 2016; Becker et al. 2017), most commonly by using the R-package 'mgcv' (Wood 2015).

2.4.1 GAMs

Generalized additive models are advantageous to modeling natural phenomena as they enable the modeling of complex and nonlinear relationships between the response variable and the predictors. This is possible due to several inherent properties in the structure of GAMs.

1) The response variable is not required to have a normal or gaussian distribution, GAMs enable the use of a link-function that bridges the true distribution of response variable with the computation of the model.

2) The model does not assume a linear relationship between the response variable and the explanatory variables. This is possible due to the use of smoothing parameters, which allow segmentation of the explanatory variables into several sections (basis functions), each of which is fitted separately to the response variable and brought back together to create a consecutive relationship (Figure 7). Although this method presents a risk of overfitting the data, the model is equipped with several outputs that enable validation of the results and monitoring for overfitting.

3) The "additive" aspect of the model refers to the construction of a singular model with several explanatory variables, whose effects add up to jointly explain the response variable.

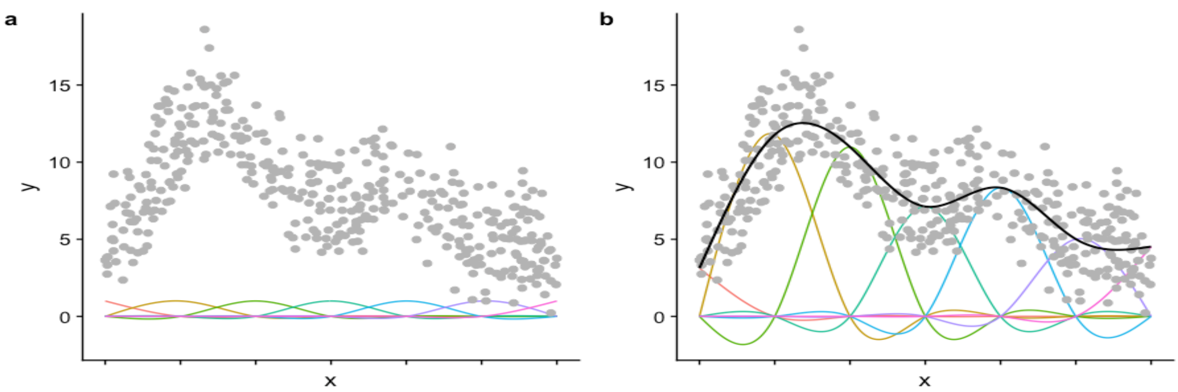


Figure 7. Visualization of the multiple basis functions that make up a single smoothed function, describing the relationship of the response variable with one of the explanatory variables in each segment. Image taken from 'Noam Ross – GAMs in R online course'.

The GAMs equation:

$$F(x) = y = \beta_0 + f_1(x_1) + f_2(x_2) + \ldots + f_r(x_r)$$

2.4.2 Challenges of the Dataset

Opportunistically Collected Data

Due to the opportunistic nature of the data collection, the survey effort was not uniform across the study area. Additionally, ship tracks were often unsystematic, therefore not allowing for construction of the dataset according to track segments, as is typically done in this type of work. In order to create a dataset that is adjusted to the unsystematic tracks, yet includes the entire array of environmental variables chosen, fragmentation of the tracks was created according to the 2 x 2 km grid cells described in Chapter 2.1.

Over-Dispersed and Zero-Inflated Data

The result of this high-resolution fragmentation created a dataset with 25,464 rows of data, out of which only 284 contained *T. truncatus* sightings (1%), and an additional dataset (of the south portion only) with 17,007 rows of data, out of which only 40 contained *D. delphis* sightings (0.2%). As a result of the paucity of the data, as detailed above, the data was heavily zero-inflated. Initially, a Binomial distribution, describing the presence or absence of dolphins as 0 or 1, was defined for the response variable, as the main interest of this work was to determine dolphin presence in light of varying environmental conditions. However, Binomial distribution is not known to cope well with zero-inflated data and results showed that this distribution was not able to capture the variability of the dataset due to the high portion of zeros in the data.

Another distribution available in the 'mgcv' package is Zero-Inflated Poisson, which models the data in two phases- 'phase one' models the presence/absence data to determine the conditions during which the non-zero results may be obtained, and 'phase two' models the count data in order to determine the number of occurrences once initial non-zero conditions are met (Barry et al., 2002). This distribution presents a good fit for ecological data as it accounts for the two types of zero values in the dataset – true zeros, and apparent zeros that would be reported in the data, if not for some type of masking process (Ridout et al., 1998). In the case of ecological surveys, the apparent zeros relate to instances when a species or organism is present but is not sighted or recorded by the observers due to perspective bias or availability bias. Perspective bias refers to the subjective limitations of an observer on watch, who cannot possibly be attentive to the entire survey area at all times, resulting in occasional "missed sightings". Availability bias refers to the availability of the species / organisms to be detected, which comes into effect in the case of dolphins when they are submerged and cannot be seen from the surface (Marsh et al., 1989; Mannocci et al., 2017).

Following further investigation of the dataset by use of several tests, the data was also found to be over dispersed, with its variance being much higher than its mean, causing a Poisson distribution to be inappropriate. Negative Binomial distribution is known to cope best with over dispersed data (Bliss et al., 1953; Thurston et al., 2000), and ideally a Zero-Inflated Negative Binomial distribution would have been used for modeling (Barry et al., 2002; Minami et al., 2007), however this distribution is currently unavailable in the 'mgcv' package, which is the most established and widely used package for GAMs modeling in the environmental sector. An additional distribution that is available in the 'mgcv' package is the Tweedie distribution, which is a special case of exponential distributions that have a cluster of data at zero. This is a useful distribution for ecological data where the organisms tend to be clustered so many individuals may be observed together or none at all, and this has been previously used in cetacean density modeling (Mannocci et al., 2017) as well as density modeling for other species of marine life (Candy 2004; Shono 2008; Peel et al. 2013).

For comparison purposes, three models were run, two times each – once using the Tweedie distribution and once using the Negative Binomial distribution, in order to evaluate results and attempt to choose the most appropriate distribution. The three models evaluated were 1) the full dataset 2) data from the years 1999-2009 3) data from the years 2010-2019. Using stepwise selection, based on Akaike Information Criterion (AIC) where smaller values are indicative of the model being of better quality - the final variables were chosen for each of the models. The Negative Binomial based models retained several additional explanatory variables when compared to the Tweedie models (Table 1), and the trends in the individual plots displayed overall similarity (Appendix A). This comparison was ultimately insufficient for determination of most appropriate distribution for the models, as AIC is incomparable between these two distributions, and higher 'deviance explained', indicative of goodness-of-fit from 0 – 100, is not necessarily an indication of a better fitting model, as high 'deviance explained' could be a result of overfitting due to a deficient dataset. For this reason, all models were run using both distributions, and a comparison between results was made throughout this work.

Table 1. Model comparison of three main models; 1) All Data, 2) 1999-2009, and 3) 2010-2019, for Negative Binomial distribution and Tweedie distribution.

Model name	N dolphin observations	N Zero	% non zero	N variables	% Deviance Explained	AIC	Variable Included
All Years - TW	284	2362	12.02	7	21	4278	DESAL + SEARCHING + SLOPE + DEPTH + SST + NUTRIENTS + WRECK
1999-2009 - TW	113	1850	6.11	6	18	2474	SEARCHING + SST + SHORE + DESAL + SLOPE + DEPTH
2010-2019 - TW	171	2028	8.43	4	26	3098	DESAL + SHORE + SEARCHING + SST
All Years - NB	284	2362	12.02	7	23	3134	DESAL + SEARCHING + SHORE + DEPTH + SST + BOTTOM + SLOPE
1999-2009 - NB	113	1850	6.11	8	23	1391	SEARCHING + SHORE + DESAL + DEPTH + WRECK + SLOPE + BOTTOM + SST
2010-2019 - NB	171	2028	8.43	6	31	1988	DESAL + SST + SHORE + SEARCHING + DEPTH + NUTRIENTS

Statistical Distribution Selection

<u>*Negative Binomial Distribution*</u>

Binomial distribution is defined by the following conditions: 1) fixed number of trials (n) 2) each trial is independent 3) only two outcomes are possible 4) probability of success for each trial (p) is constant 5) a random variable Y = number of successes. In a Negative Binomial distribution, the number of trials in not fixed, and the random variable Y = the number of trials needed to achieve r successes (Fisher 1941). Although this description originates from the field of combinatorics and does not describe with precision the way this distribution is utilized in ecological models, it aids in creating a general understanding of the properties of these distributions. An additional way of viewing the difference between the two distributions - in contrast to the Binomial distribution which would refer to the number of dolphin sightings given a fixed amount of survey effort; the Negative Binomial distribution refers to the amount of survey effort required to produce a dolphin sighting. This distribution is commonly utilized for over-dispersed data, meaning the dataset presents greater variability than would be expected for a given statistical model.

The Negative Binomial Formula (Probability Mass Function):

$$f(k;r,p) \equiv \Pr(X=k) = \binom{k+r-1}{r-1}(1-p)^k p^r$$

p = probability of success, r = number of successes, k = number of failures

<u>*Tweedie Distribution*</u>

The Tweedie distribution is a special case of an exponential distribution, which describes time between events in a Poisson process. The Tweedie distribution differs from a regular exponential distribution by enabling the inclusion of many data items at zero. Essentially, if plotted on a histogram, Tweedie distribution display a plot similar to a regular exponential distribution, with an additional spike at zero. The probability density function for the Tweedie distribution is complex and cannot be expressed as a single expression (Dunn et al., 2005).

Data Modification (as an Adaptation for Modeling)

Some minor manipulations were performed on the sightings data to improve the performance of the models- all group sightings that were originally recorded between 9-12 individuals were categorized as 10, all sightings originally recorded between 13-17 individuals were categorized as 15, and all sightings originally recorded as 18 or above were categorized as 20 (Figure 8). This grouping method enabled the models establish significance in more explanatory variables as it minimized the over-dispersion of the data. This modification presents a reasonable change in the data set, as all group sizes were estimated in the field in real time, with smaller groups typically estimated more accurately, and no available measures for verification of accuracy.

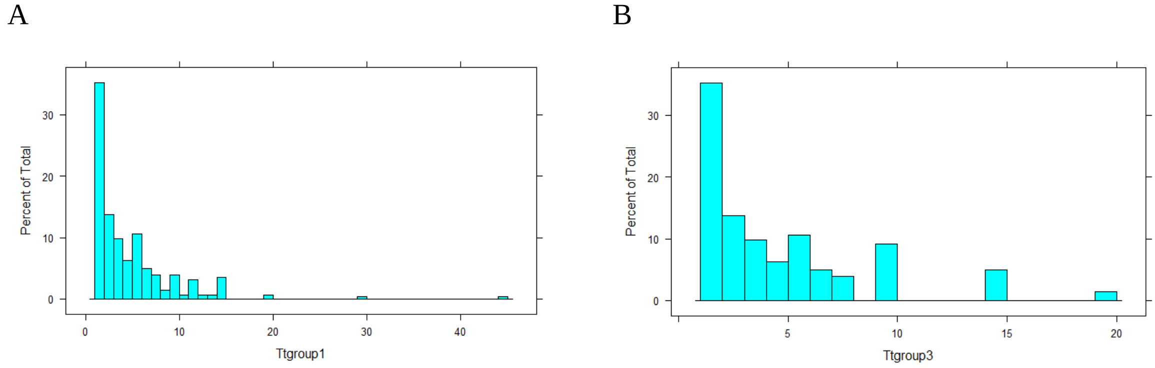


Figure 8. A) Histogram of *Tursiops truncatus* observed group sizes before modifications for modeling purposes. B) Histogram of *Tursiops truncatus* group sizes following modification for modeling purposes.

An additional modification was made across most subsets of the data (subsets specified later in this chapter) in order to better cope with the artificial inflation of zeros in the datasets. Much of the zero inflation was "artificial", resulting from the data-collection method and the small (grid) cell size chosen. This modification used to counter some of the zero-inflation was the randomized reduction of survey effort in all subsets. This was done by selecting a random a portion (every n^{th} row) of the survey effort data (sections where no sightings occurred) thereby decreasing the proportion of zeros in the subset. The randomized reduced-zero subsets were compared between them and compared with the full dataset across each explanatory variable. Plots of the relationship between the predicted variable and explanatory variables displayed similar trends, thereby confirming that this reduction of zeros did not skew the model results. Overall, the reduction of zeros aided in detecting true significance in occurrence patterns rather than apparent significance correlating with absence patterns.

2.4.3 Explanatory Variable Selection

The full set of predictive variables was examined for collinearity, and if two variables presented a collinearity index higher than 0.7, one was removed (Gilles, 2009). Multiple models were constructed and variable selection for each was performed using stepwise selection, based on AIC and 'deviance explained'.

The inclusion of 'chlorophyll *a*' data (ranging 0.025-0.183 mg/m^3) in models was carefully examined due to the partial coverage of this variable across the dataset. The cost of including 'chlorophyll *a*' data is that all near shore data is eliminated from the model, including 11% of all sightings. Similar to the evaluation process used to assess statistical distribution to be used for modeling, three models were run but only for grid cells for which chlorophyll *a* data were available. These models were based on the Negative Binomial distribution and during the variable selection process 'chlorophyll *a*' was one of the least significant explanatory variables. Most models attempting to include 'chlorophyll *a*' resulted in high AIC values, and ultimately 'chlorophyll *a*' was only retained in the final model of 1999-2009, in which this variable was ultimately not significant. Table 2 shows the results obtained, with the same analysis for the entire dataset (lower part of Tale 1) included again, for comparison, The models that included 'chlorophyll *a*' could not be compared to those without chlorophyll *a* by use of AIC, but two of the three models presented lower % deviance explained (Table 2). Individual variable plots for both sets of models presented overall similar trends, though several variables were not retained in the models that included 'chlorophyll *a*' (**Appendix** #). The results of all attempts to include 'chlorophyll *a*' led to the conclusion that the inclusion of this variable in the *T. truncatus* dataset does not have a significant enough contribution to modeling to compensate for the loss of data that is a byproduct of this inclusion, and therefore, it is preferable to run models without use of 'chlorophyll *a*' data.

As previously mentioned, 'chlorophyll *a*' measurements were not utilized in the *D. delphis* dataset as there is lack of coverage for this parameter (from satellite data) in the nearshore waters, and data-model results were not available for the year 2020 during the time modeling was conducted for this study.

Table 2. Model comparison of three main models; 1) All Data, 2) 1999-2009, and 3) 2010-2019, for datasets with and without 'chlorophyll *a*' data.

Model name	N dolphin observations	N Zero	% non zero	N variables	% Deviance Explained	AIC	Variable names
All Years CHL	252	2062	12.22	6	21	2786	DESAL + SEARCHING + SHORE + SST + BOTTOM + SLOPE
1999-2009 CHL	99	1681	5.89	8	25	1223	SEARCHING + SHORE + DEPTH + DESAL + WRECK + SLOPE + SST + CHL
2010-2019 CHL	153	1737	8.81	5	26	1775	DESAL + SST + SHORE + SEARCHING + DEPTH
All Years	284	2362	12.02	7	23	3134	DESAL + SEARCHING + SHORE + DEPTH + SST + BOTTOM + SLOPE
1999-2009	113	1850	6.11	8	23	1391	SEARCHING + SHORE + DESAL + DEPTH + WRECK + SLOPE + BOTTOM + SST
2010-2019	171	2028	8.43	6	31	1988	DESAL + SST + SHORE + SEARCHING + DEPTH + NUTRIENTS

2.4.4 Data Sub-Sets

Data Sub-Sets (Tursiops truncatus)– Spatial

Additional subsets of the data were created to examine temporal and spatial differences. The spatial datasets were created by dividing the study area into five areas, according to their environmental characteristics and their search area coverage (Figure 9). **Area 1** consists of water to the north of the Haifa Bay, and up to the most northern point (the border with Lebanon). This area includes the deep Achziv Canyon and is composed of courser sand, originating from calcareous sandstone (locally termed *kurkar*) ridges, in comparison to the rest of the coastline that is characterized by quartz sand from the Nile River (Zviely et al., 2007). A total of 3,672 km were surveyed across 'Area 1' throughout the entire study period. **Area 2** consists of the Haifa Bay area, which is the sink area for the quartz sand, and in the past, one of the most polluted areas in Israel due to chemical waste dumped in the Kishon River flowing into the bay. Although there is a harbor in Haifa, very few surveys have been conducted in this area, and few dolphins have been observed, though data from the public suggests that dolphins do frequent this region. A total of 2,341 km were surveyed across 'Area 2' throughout the entire study period. **Area 3** is a long and uniform section of the coastline that has received little attention during designated surveys, as there are no publicly accessible harbors/anchorages along that entire region. A total of 6.273 km were surveyed across 'Area 3' throughout the entire study period. **Area 4** is similar to 'Area 3' in terms of environmental conditions; however, 'Area 4' contains three large marinas out of which many designated surveys departed. A total of 14,304 km were surveyed across 'Area 4' throughout the entire study period. **Area 5** is the most southern area, it is closest to the Nile River, and the sediment is siltier than other parts of the coastline. This area is the heart of *D. delphis'* area of occurrence and has been regularly studied via designated surveys only in the last ~5 years. A total of 3,397 km were surveyed across 'Area 5' throughout the entire study period.

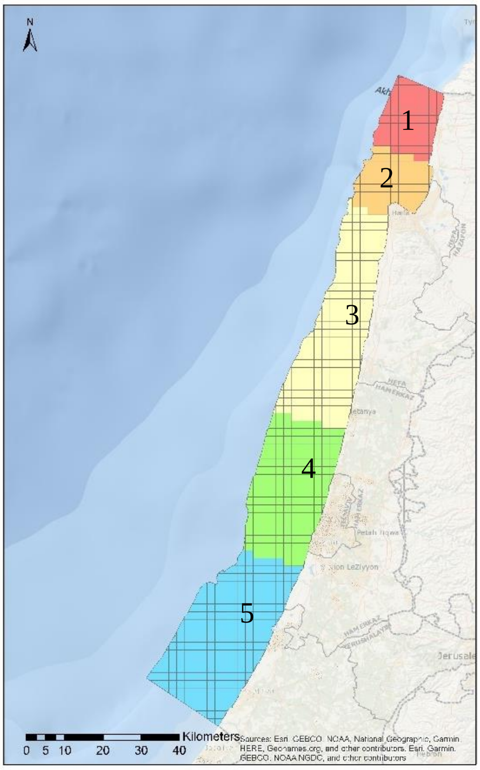


Figure 9. Map displaying the five sections of the study area

Data Sub-Sets (Tursiops truncatus) - Temporal

Two types of temporal subsets were created- seasonal and long term (multi-year). Although number of sightings were evenly distributed between months (Table 3), seasonal variability was examined by dividing the year into a 'Hot' and 'Cold' season, relating to the typical water temperature measured during that month. 'Cold' months consisted of December through May, when water temperature median was 19 °C, and ‘Hot’ months consisted of June through November when temperature median was 29 °C (**Figure** 10). Survey effort was comparable between these two seasons as 18,002 km were surveyed during the ‘Cold Season’, and 21,648 km during the ‘Hot Season’.

Table 3. Number of *Tursiops truncatus* sightings during each month of the year, across the 1999-2020 study period

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tt sighting	27	18	12	27	26	31	21	29	27	34	32	22

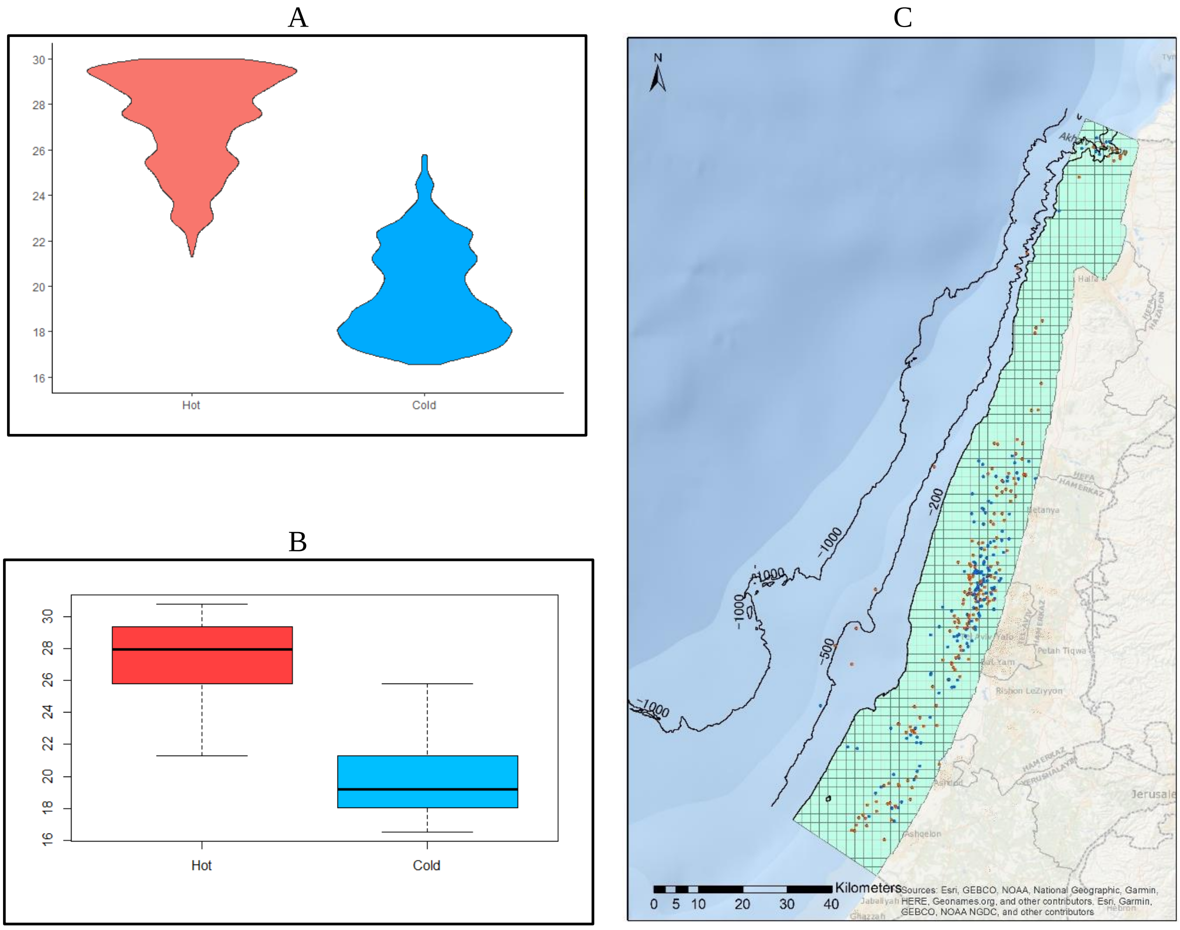


Figure 10. A) Violin plot of all sea surface temperatures included in the dataset between 1999-2019, derived from satellite data. B) Box plot of all sea surface temperatures included in the dataset between 1999-2019, derived from satellite data. C) Distribution of *Tursiops truncatus* sightings across the study area during the ‘Hot Season’ (red dots) and ‘Cold Season’ (blue dots).

The second temporal subset was created by dividing the study period to two periods: first decade (1999-2009) and second decade (2010-2020). Some differences are expected to arise between these two periods of time, as total survey effort increased in the second decade, particularly in ‘Area 5’ (**Figure** 11).

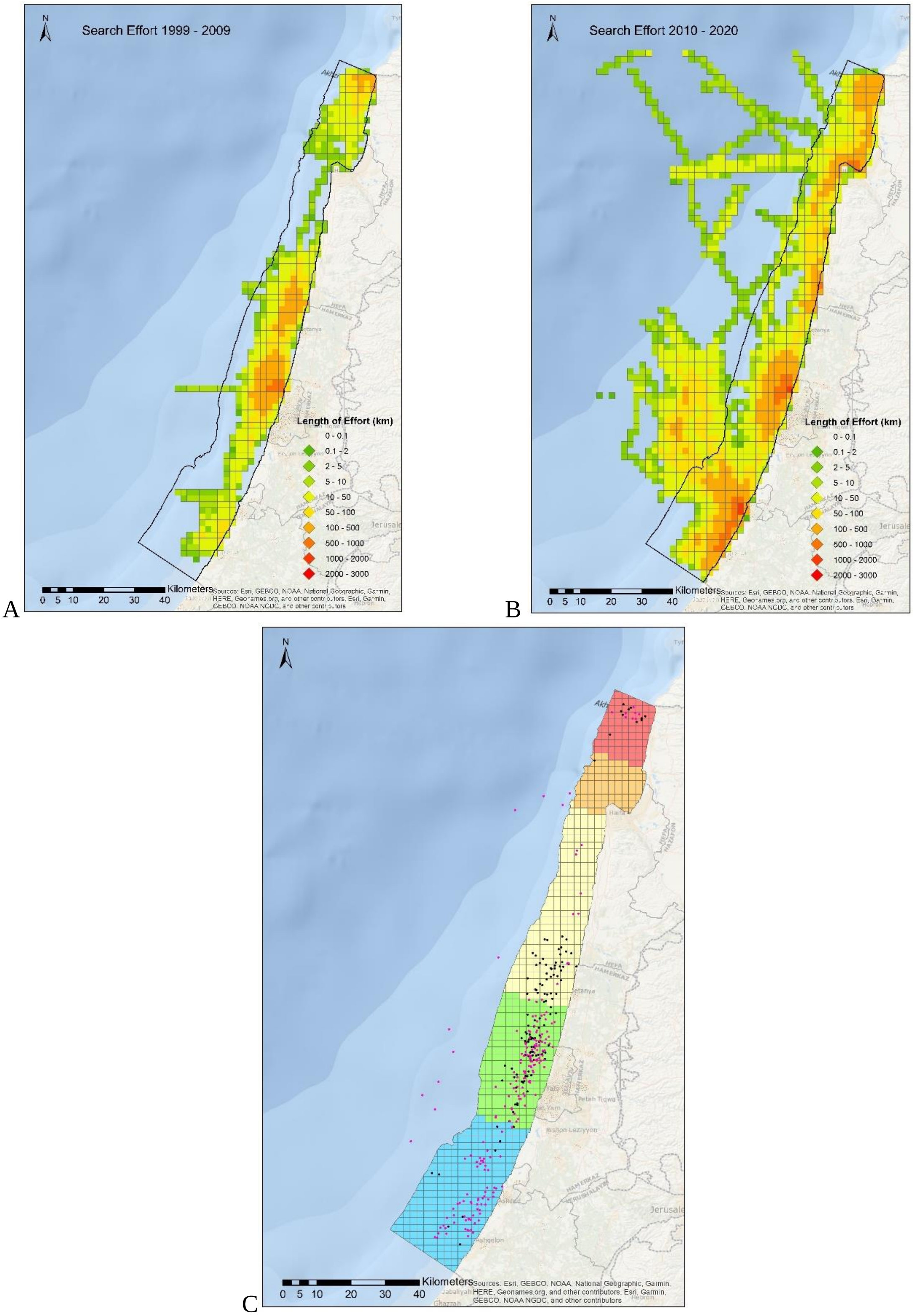


Figure 11. A) Survey effort across the study area during the years 1999-2009. B) Survey effort across the study area during the years 2010-2020. C) Sightings during the years 1999-2009 in black, sightings during the years 2010-2019 in magenta, with the 5 section division in the background.

Data Sub-Sets (Tursiops truncatus)– Trawler Excluded Data

In order to differentiate between dolphin occurrences that are directly associated with man-made food resources (trawler nets and fish farms) and the natural environment, a subset was created that only included data not-related to either resource. Essentially, this subset only includes data that was collected during "neutral" searching conditions, not effected by anthropogenic food sources. Models constructed from this subset reflect *T. truncatus'* spatial preferences in relation to different habitat, as defined by (mostly) natural variables.

Data Sub-Sets (Delphinus delphis) – Temporal

The first recorded *D. delphis* sighting in the study area occurred in 2009, followed by a second sighting during the same year, and two additional sightings in 2011. After 2011, this species was not sighted during any surveys, until 2016, when sighting in the south region began to be a regular occurrence. Additionally, three of the early sightings (2009 and 2011) occurred between Herzelia and Jaffa, while all other sightings occurred further south, between Ashdod and Ashkelon. Due to the temporal inconsistency of *D. delphis* sightings, three subsets were created for modeling this species' distribution and occurrence, in an attempt to minimize noise in the data and create models that reflect the true environmental drivers for its distribution.

- Subset 2009 – geographically spans the entire *D. delphis* extent of distribution ('Dd Area', Figure 1) and includes data from the years 2009, 2011, and 2016-2020.
- Subset 2016 – geographically spans the entire *D. delphis* extent of distribution ('Dd Area', Figure 1) and includes data from the years 2016-2020.
- Subset 2016, Area 5 – geographically spans the extent of 'Area 5' (Figure 9) and includes data from the years 2016-2020.

Data Sub-Sets (Tursiops truncatus & Delphinus delphis) – Non Correlated Data

In an attempt to minimize the variation in the dataset and improve model results, several subsets were created that only included grid-cells in which the occurrence of dolphin observations was not statistically correlated to search effort (similar to the process describe in Chapter 2.3.2, prior to the plotting of the 'Occurrence Maps'). Utilizing Spearman's Rank Correlation Test, a threshold relating to 'minimum survey effort per grid-cell' was determined. Only grid-cells containing accumulative survey effort (total km) that exceeded the threshold were retained in these subsets. Overall, percent of data retained from the entire data set varied between 33-42%, and percent of sightings retained varied between 31-37%.

Data Sub-Sets – General Inherent Effects

Sub-setting the data has a several effects on the resulting models. Some subsets included such a small amount of data that results were over-fitted and unreliable or that randomly reducing the number of zero values was not possible. Also, categorical variables are permitted to contain only one category with all zero values. If multiple categories contain all zero values they must be merged with other categories or removed, otherwise the model will not run. Throughout some subsets, not all categories contained non-zero values and had to be merged, thereby creating a certain bias within categorical predictors, particularly ‘Bottom Type’.

2.4.5 Model Selection

Stepwise variable selection was performed on each of the data sub-sets, to construct multiple models. The multitude of models resulting from these subsets allowed for examination of the differences in results and significant explanatory variables between them.

Models were constructed for a) the entire dataset (across all years, and across both decades) b) the ‘Hot Season’ and ‘Cold Season’ datasets (across all years, and across both decades) c) the five spatial subsets (across all years, and across both decades).

2.4.6 Model Verification

Model verification is often performed by eliminating a portion of the original dataset during model construction, and later comparing this portion of the data with model predictions (Gilles 2008; Gilles et al., 2011; Druon et al., 2012). This method was considered, but not performed during this work due to the small number of sightings included in the dataset, which did not leave any data “to spare”.

3.1 POPULATION SIZE ESTIMATION

3.1.1 Estimation Based on concepts from Distance Sampling

The encounter rate of *T. truncatus* between 1999-2000 was found to be 0.77 sightings per 100 km of survey effort. Average density of this population between 1999-2000, utilizing ESW, was estimated at 0.06 individuals per km^2, with a derived total abundance of 135 ± 15 individuals (± 95%CI).

Population size estimation of *D. delphis* between 2009-2018 found the encounter rate of this species to be 0.11 sightings per 100 km of survey effort. Density of *D. delphis* population was estimated at 0.028 per km^2, and total abundance 42 ± 13 individuals (± 95%CI). An updated population size estimation for 2009-2020 found the encounter rate of *D. delphis* to be 0.19 sightings per 100 km of survey effort. Density of this population between 2009-2020 was estimated at 0.06 per km^2, and total abundance of 79 ± 11 individuals (± 95%CI).

3.1.2 Model Based Estimation

Population size estimations of *T. truncatus* were produced from two sets of models; Negative Binomial based, and Tweedie based. Models for three time periods were constructed for each distribution; 'All Years', '1999-2009' and '2010-2019', with the results presented in Table 4.

Model based estimations for *D. delphis* were not produced due to the small dataset which resulted in models that are overall unreliable for the purpose of abundance estimation.

Table 4. Summary of abundance estimations for *Tursiops truncatus* population during the years 1999-2019 ('All Years'), 1999-2009 and 2010-2019 based on models utilizing Negative Binomial and Tweedie distributions.

Time Period	Statistical Distribution of Model	Estimated Abundance (number of individuals)
All Years	Negative Binomial	30.5 ± 35.8
1999-2009	Negative Binomial	17.5 ± 28.8
2010-2019	Negative Binomial	26.6 ± 105.5
All Years	Tweedie	31.1 ± 65.9
1999-2009	Tweedie	19.5 ± 16.4
2010-2019	Tweedie	17.8 ± 16.8

3.2 OCCURANCE MAPS

3.2.1 Spatial Occurrence Maps

'Mgcv' package supports the creation of occurrence plots, which display probability of occurrence across the geographical space, based on the coordinates of the observations. The results are displayed as a contour plot, colored similarly to a heat map, but due to lack of spatial references (coastline, cities etc.) these plots are challenging to interpret. In order to create more interpretable occurrence maps, the output from spatial models (modeling based only on geographical coordinates of sightings, regardless of survey effort) were plotted in ArcGIS, as described in Chapter 2.1.2. These maps essentially display the same results as the 'mgcv' package plots and present the change in occurrence probability across the geographical space. Models were created based on both Negative Binomial and Tweedie distribution, for *T. truncatus* and *D. delphis*, and the difference in results reflects the difference in interpretation of the data according to these two distributions (Figure 12).

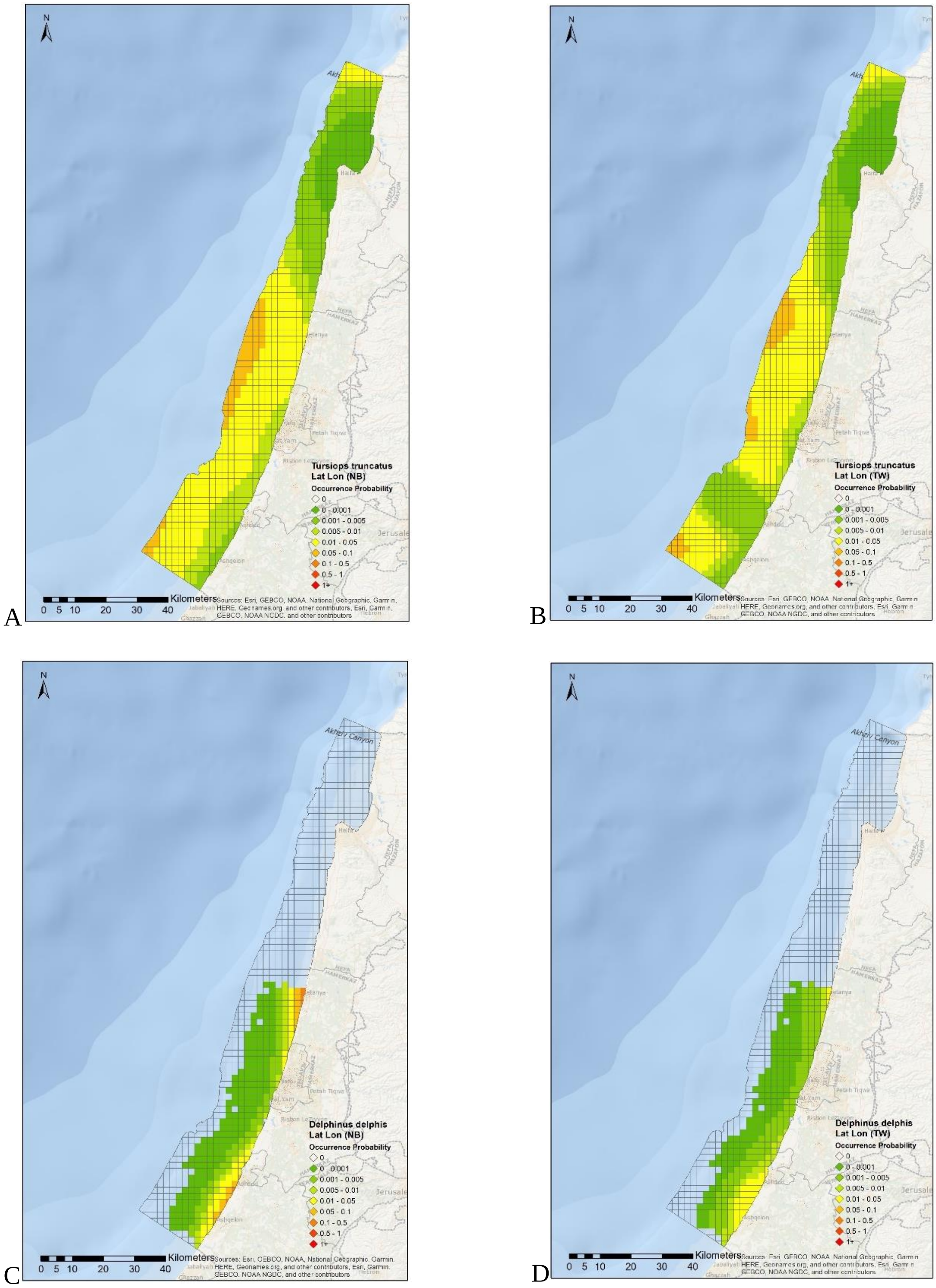


Figure 12. A) Prediction map of *Tursiops truncatus* between the years 1999-2019, along the Mediterranean continental shelf of Israel, from Negative Binomial spatial model in 'mgcv' package, plotted in ArcGIS. **B**) Prediction map of *Tursiops truncatus* between the years 1999-2019, along the Mediterranean continental shelf of Israel, from Tweedie spatial model in 'mgcv' package, plotted in ArcGIS. **C**) Prediction map of *Delphinus delphis* during the years 2009, 2011, 2016-2020, along the Mediterranean continental shelf of Israel, from Negative Binomial spatial model in 'mgcv' package, plotted in ArcGIS. **D**) Prediction map of *Delphinus delphis* during the years 2009, 2011, 2016-2020, along the Mediterranean continental shelf of Israel, from Tweedie spatial model in 'mgcv' package, plotted in ArcGIS.

3.2.2 Non-Correlated Data Occurrence Maps

Utilizing the ‘non-correlated data’ that was retained following the Spearman’s Correlation test analysis, an additional set of occurrence maps was created. These maps display the ‘number of dolphin sightings – normalized to survey effort’, and overall effort, only in sections that surpassed the no-correlation threshold.

Tursiops truncatus

The data collected for *T. truncatus* was divided into two time periods (1999-2009, 2019-2019), each of which was analyzed separately for correlation, and mapped in a separate plot.

During the years 1999-2009 a minimum of 21 km (accumulated per grid-cell) was required in order for dolphin sightings within a grid-cell to be significantly un-correlated to survey effort (rho = 0.168, p = 0.054). Also, during these years, the values of ‘number of sightings – normalized to survey effort’ ranged between 0.004-0.1 sightings per km of survey effort (Figure 13A).

During the years 2010-2019 a minimum of 58 km (accumulated per grid-cell) was required in order for dolphin sightings within a grid-cell to be significantly un-correlated to survey effort (rho = 0.169, p = 0.55). Also during these years, ‘number of sightings – normalized to survey effort’ values that ranged between 0.03-0.004 sighting per km of survey effort (Figure 13B).

A B

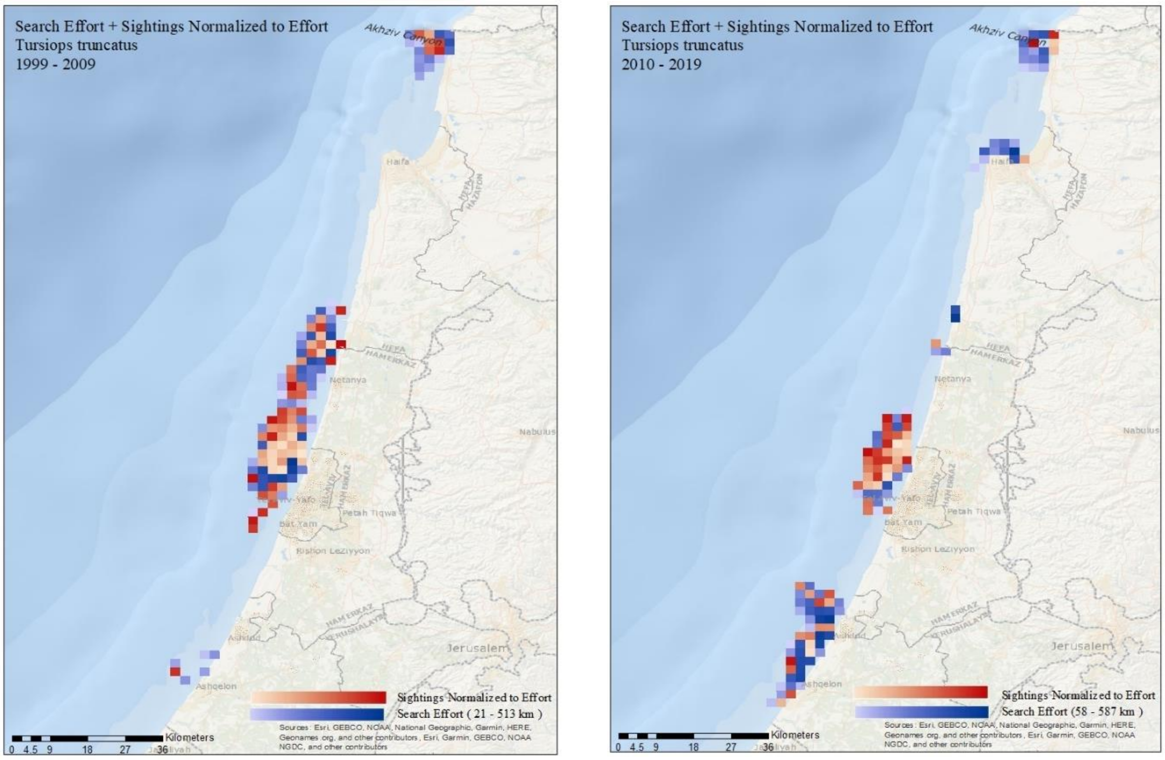


Figure 13. A) Map of study area, displaying survey effort and *Tursiops truncatus* sightings (normalized to survey effort), presenting only grid-cells with sufficient survey effort to surpass the correlation threshold, during the years 1999–2009. B) Map of study area, displaying survey effort and *Tursiops truncatus* sightings (normalized to survey effort), presenting only grid-cells with sufficient survey effort to surpass the correlation threshold, during the years 2010-2019.

Delphinus delphis

The data collected for *D. delphis* was analyzed and mapped for the time period between the years 2010-2020. During the years 2010-2020 a minimum of 96 km (accumulated per grid-cell) was required in order for dolphin sightings within a grid-cell to be significantly un-correlated to survey effort (rho = 0.249, p = 0.061). Also, during these years, 'number of sightings – normalized to survey effort' values that ranged between 0.001-0.015 sighting per km of survey effort (Figure 14).

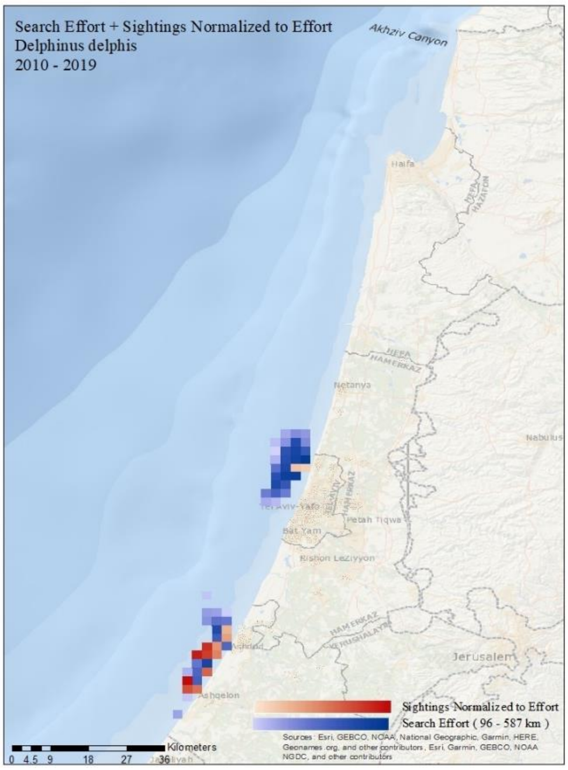


Figure 14. Map of study area, displaying survey effort and *Delphinus delphis* sightings (normalized to survey effort), presenting only grid-cells with sufficient survey effort to surpass the correlation threshold, during the years 2010-2020 in the southern region of Israel.

3.3 MODELS - TURSIOPS TRUNCATUS

Models were constructed for many subsets of the data, as described in Chapter 2.4.4.

3.3.1 Spatial and Temporal Models

Models constructed of spatial or temporal subsets of the main dataset, based on Negative Binomial distribution, presented deviance-explained values that varied between 8% and 13%, while number of explanatory variables varied between 3 and 8 (Table 5). Of 21 models, the explanatory variables that were retained in the highest number of models were 'Searching' (19 models), 'Sea Surface Temperature' (16 models), 'Distance to Desal or Power Plants' (14 models), 'Distance to Shore' (13 models), 'Depth' (12 models), 'Distance to Rivers or Artificial Nutrient Sources' (10 models), 'Bottom Content' (10 models), 'Artificial Submerged Structures' (9 models) and 'Slope' (6 models).

Models constructed of spatial or temporal subsets of the main dataset, based on Tweedie distribution, presented deviance-explained values that varied between 1% and 50%, while the number of explanatory variables varied between 1 and 7 (Table 5). Of 21 models, the explanatory variables that were retained in the highest number of models were 'Searching' (17 models), 'Distance to Desal or Power Plants' (11 models), 'Sea Surface Temperature' (7 models), 'Depth' (6 models), 'Slope' (4 models), 'Distance to Shore' (3 models), 'Artificial Submerged Structures' (2 models), 'Distance to Rivers or Artificial Nutrient Sources' (1 model), and 'Bottom Content' (1 model).

Full Data Set and Decade-long Subsets

Negative Binomial - Across the temporal subsets, the variables 'Distance to Desal or Power Plants', 'Distance to Shore', 'Sea Surface Temperature' and 'Searching' were significant for all three time periods; 'All Years', '1999-2009', and '2010-2019' (Table 6).

The 'Distance to Desal or Power Plants' plots for the 'All Years' and '2010-2019' models displayed a rising trend across the first few kilometers with varying uncertainty, followed by a decline to a probability of dolphin occurrence of nearly zero, while the '1999-2009' model presented an overall gradual declining trend. The 'Distance to Shore' plot displayed overall low probability of dolphin occurrence across the three temporal models, though in the 'All Years' model and '1999-2009' model, a rise in probability of occurrence is notable between distances of 5-10 km from shore. However, all three 'Distance to Shore' plots display high uncertainty at one end of the data (either near shore or very far). The 'Sea Surface Temperature' plots for the 'All Years' and '2010-2019' models displayed considerable wiggliness and were likely overfitted. 'Searching' displayed consistently higher dolphin occurrence in the vicinity of trawlers when compared to areas without presence of trawlers.

Other significant variables include 'Slope', which was significant during the 'All Years' model and the '1999-2009' model, with both plots displaying increasing probability of dolphin occurrence, along with increasing uncertainty as slope increased. 'Depth' was only significant during the '2010-2019' model and presented a dramatic rise in probability of dolphin occurrence and in uncertainty at approximately 200 m depth, though very few sightings were recorded at this depth, highlighting the unreliability of this trend. ‘Bottom Content’ was only significant during the ‘All Years’ model and the plot displayed varying probability of dolphin occurrence between the different habitat and sediment types. Lastly, ‘Artificial Submerged Structures’ was significant during the ‘1999-2009’ model and presented higher probability of dolphin occurrence in the vicinity of submerged structures.

Tweedie – Similarly to the Negative Binomial models, across the temporal subsets, the variables ‘Distance to Desal or Power Plants’, ‘Distance to Shore’, ‘Sea Surface Temperature’ and ‘Searching’ were significant for all three time-periods: ‘All Years’, ‘1999-2009’, and ‘2010-2019’. The trends observed for these variables were also similar to those observed for the Negative Binomial Models (Table 6).

Other significant variables include ‘Slope’, which was significant during the ‘1999-2009’ model, with a plot displaying increasing probability of dolphin occurrence, along with increasing uncertainty as slope increased, ‘Depth’, which was significant during the ‘All Years’ model and presented a rise in probability of dolphin occurrence and in uncertainty as depth increased, though very few sightings were recorded at depths greater than 100 m. ‘Distance to Rivers or Artificial Nutrient Sources’ was significant during the ‘All Years’ model and the plot displayed a decline in probability of occurrence up to a distance of 10 km, followed by a rise, and also a rise in uncertainty.

Hot / Cold Seasons

Negative Binomial - During the ‘Hot Season’ the ‘Searching’ variable was significant for all three time periods and all plots displayed higher probability of dolphin occurrence in the vicinity of trawlers (Table 7). ‘Distance to Desal or Power Plants’ was significant for the ‘All Years’ model and the ‘2010-2019’ model, and similar to the temporal models, probability of dolphin occurrence across the first few kilometers was slightly higher and more variable than at greater distances. ‘Sea Surface Temperature’ was significant during the ‘All Years’ model and ‘2010-2019’ model and in both cases a rise in probability of dolphin occurrence is notable at approximately 22° C, and high uncertainty is evident at approximately 28° C. ‘Bottom Content’ was significant during the ‘All Years’ model and the ‘2010-2019’, displaying difference in probability of dolphin occurrence between the different habitat and sediment types. ‘Distance to Shore’ was only significant in the ‘1999-2009’ model and displayed over low probability of dolphin occurrence, with a slight rise between 8-10 km from shore. ‘Distance to Rivers or Artificial Nutrient Sources’ was significant during the ‘1999-2009’ model and displayed low probability of dolphin occurrence across the whole plot. ‘Artificial Submerged Structures’ was significant during the ‘1999-2009’ model and presented lower probability of dolphin occurrence in the vicinity of submerged structures.

Tweedie – Similarly to the Negative Binomial models, during the ‘Hot Season’ the ‘Searching’ variable was significant for all three time periods, the ‘Distance to Desal or Power Plants’ was significant in the ‘All Years’ model and the ‘2010-2019’ models, and the ‘Bottom Content’ variable was significant during the ‘All Years’ model, though no additional variables were significant (Table 7).

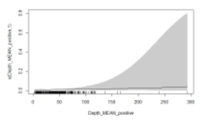
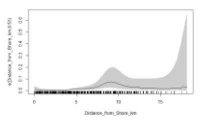
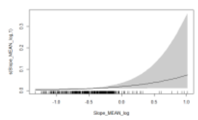
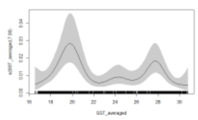
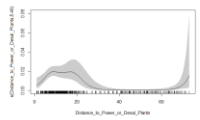
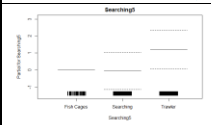
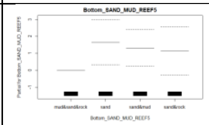
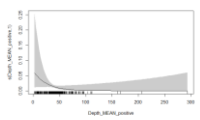
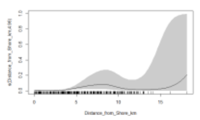
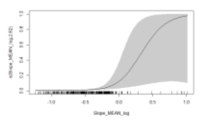
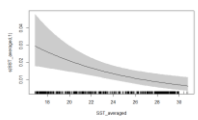
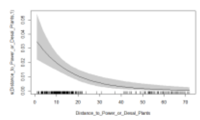
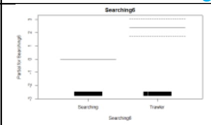
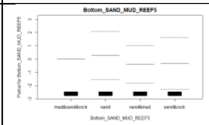
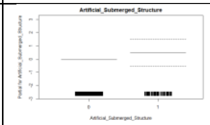
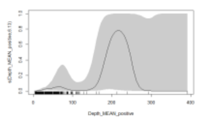
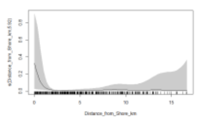
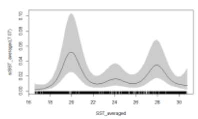
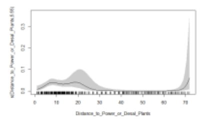
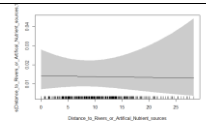
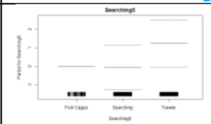
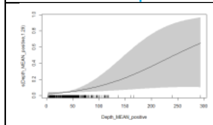
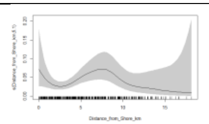
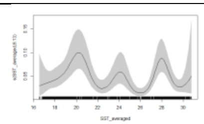
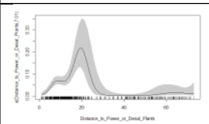
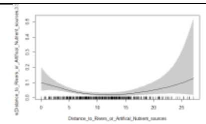
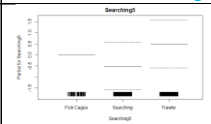
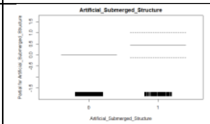
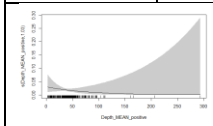
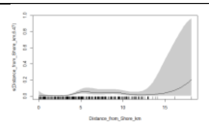
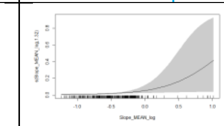
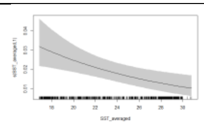
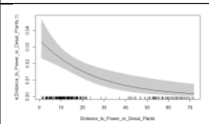
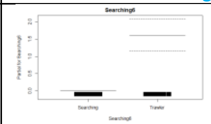
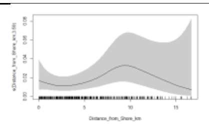
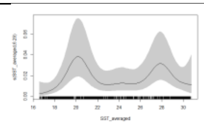
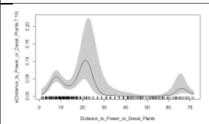
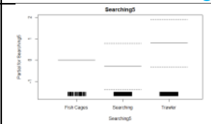
Negative Binomial - During the ‘Cold Season’ the variable ‘Distance to Desal or Power Plants’ was significant during the ‘All Years’ model and the ‘2010-2019’ model, and both plots presented a small peak in probability of occurrence at approximately 20 km. ‘Distance to Shore’ was significant during the ‘All Years’ model and the ‘1999-2009’ model, and both plots displayed a continuous rise in probability of dolphin occurrence at distances greater than 10 km, though this trend was matched with large uncertainty. ‘Sea Surface Temperature’ was significant during the ‘All Years’ model and the ‘2010-2019’ model, and both plots displayed a peak in probability of dolphin occurrence at approximately 20° C, matched with an in increase in uncertainty. ‘Distance to Rivers or Artificial Nutrient Sources’ was significant during the ‘All Years’ model and the ‘2010-2019’ model, and both plots displayed a decreasing trend as distance increased. ‘Searching’ was only significant during the ‘1999-2009’ model and presented higher probability of dolphin occurrence in the vicinity of trawlers. ‘Artificial Submerged Structures’ was also significant during the ‘1999-2009’ model and displayed higher probability of dolphin occurrence in the vicinity of submerged structures (Table 8).

Tweedie - Similarly to the Negative Binomial models, during the ‘Cold Season’ the ‘Distance to Desal or Power Plants’ variable was significant during the ‘All Years’ model and the ‘2010-2019’ model, and both plots presented similar trends to those of the Negative Binomial models. ‘Depth’ was significant during the ‘All Years’ model and the ‘2010-2019’ model and displayed increasing probability of occurrence and increasing uncertainty as depth increased. ‘Distance from Shore’ was significant during the ‘2010-2019’ model and presented a peak in probability of occurrence around 9 km from shore, while ‘Sea Surface Temperature’ was significant during the ‘All Years’ model and presented a peak around 20°C. The ‘Searching’ variable was significant during the ‘All Years’ model and the ‘1999-2009’ model and demonstrated that probability of occurrence was higher in the vicinity of trawlers, while ‘Artificial Submerged Structure’ was significant during the ‘1999-2009’ model and displayed higher probability of occurrence in the vicinity of submerged structures (Table 8). .

Table 5. Summary of final models for each sub-set. Information includes number of sightings within the subset, deviance explained for Negative Binomial based models and Tweedie based models, and names of explanatory variables for Negative Binomial based models and Tweedie based models.

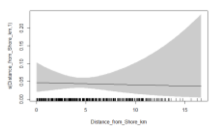
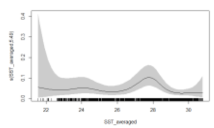
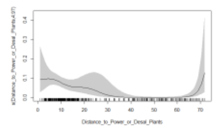
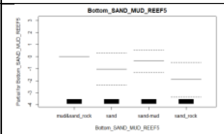
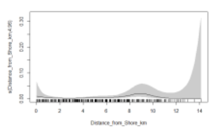
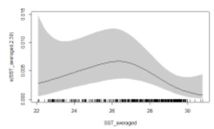
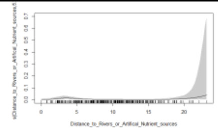
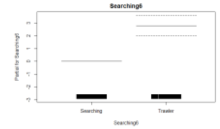
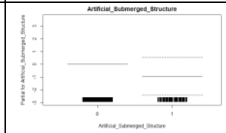
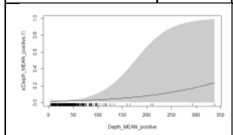
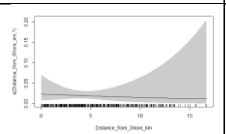
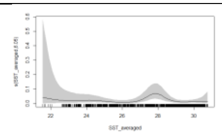
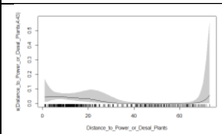
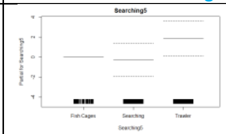
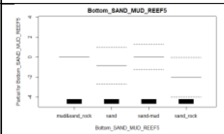
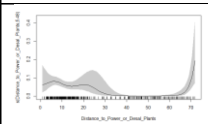
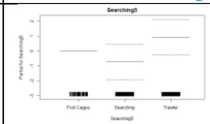
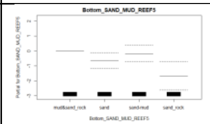
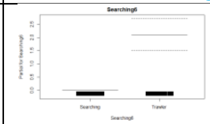
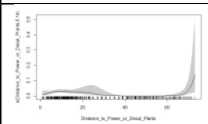
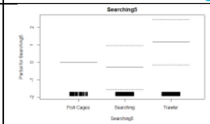
Model name	N Dolphin Observations	N Zeros	% Non-Zero	% Deviance Explained (NB)	Variable names (NB)	% Deviance Explained (TW)	Variable names (TW)
All Years	284	2362	12	23	DESAL + SEARCHING + SHORE + DEPTH + SST + BOTTOM + SLOPE	21	DESAL + SEARCHING + SLOPE + DEPTH + SST + NUTRIENTS + WRECK
1999-2009	113	1850	6.1	23	SEARCHING + SHORE + DESAL + DEPTH + WRECK + SLOPE + BOTTOM + SST	18	SEARCHING + SST + SHORE + DESAL + SLOPE + DEPTH
2010-2019	171	2028	8.4	31	DESAL + SST + SHORE + SEARCHING + DEPTH + NUTRIENTS	26	DESAL + SHORE + SEARCHING + SST
All Years HOT	154	2521	6.1	26	SEARCHING + DESAL + SST + SHORE + BOTTOM	27	SEARCHING + DESAL + BOTTOM
All Years COLD	130	2204	5.9	27	DESAL + SHORE + SST + SEARCHING + SLOPE + NUTRIENTS + WRECK	23	DESAL + DEPTH + SEARCHING + SST
1999-2009 HOT	61	2010	3	39	SEARCHING + SHORE + SST + WRECK + NUTRIENTS	16	SEARCHING
1999-2009 COLD	52	1691	3.1	18	DESAL + SHORE + WRECK + SEARCHING + SLOPE + NUTRIENTS + BOTTOM	05	SEARCHING + WRECK
2010-2019 HOT	93	2146	4.3	29	DESAL +SEARCHING + SHORE + SST + BOTTOM + DEPTH	22	DESAL +SEARCHING
2010-2019 COLD	78	1909	4.1	36	DESAL + SST + SEARCHING + NUTRIENTS + WRECK	34	DESAL + SHORE + DEPTH + SEARCHING
All Years Area 1	13	739	1.8	46	DESAL	44	DESAL + SEARCHING
All Years Area 2	1	NA	NA	NA	NA	NA	NA
All Years Area 3	43	1449	3	40	SEARCHING + DESAL + BOTTOM + DEPTH	33	DESAL + SEARCHING
All Years Area 4	172	3207	5.4	15	SST + SEARCHING + SHORE	10	SEARCHING + SST
All Years Area 5	55	2009	2.7	07	SEARCHING	5	SEARCHING
1999-2009 Area 1	5	232	2.2	38	SST	28	SLOPE + DEPTH
1999-2009 Area 2	1	NA	NA	NA	NA	NA	NA
1999-2009 Area 3	35	663	5.3	23	SEARCHING + BOTTOM + WRECK	21	SEARCHING + DEPTH
1999-2009 Area 4	65	1362	4.8	18	SEARCHING + SST	11	SEARCHING
1999-2009 Area 5	7	168	4.2	31	SST	33	SST
2010-2019 Area 1	8	507	1.6	74	DEPTH + DESAL + SEARCHING	50	DESAL + SEARCHING
2010-2019 Area 2	0	NA	NA	NA	NA	NA	NA
2010-2019 Area 3	8	786	1	72	SST + BOTTOM	18	SLOPE
2010-2019 Area 4	107	1845	5.8	15	SST + SHORE + DEPTH + SEARCHING	7	DESAL + SEARCHING
2010-2019 Area 5	48	1842	2.6	10	SEARCHING	1	SST

Table 6. Final models for *Tursiops truncatus* distribution, as run on the full dataset for all years, years 1999-2009, and years 2010-2019. First three rows display results utilizing Negative Binomial distribution, while following three rows utilize Tweedie distribution. Variables that are statistically significant have names marked in blue. All vertical axes indicate the probability of dolphin occurrence on a scale of 0 to 1 (except instances where scale is minimized for clarity), while horizontal axes are presented in the units of the relevant explanatory variable, and above the horizontal axis are markings, indicating number of non-zero observations at that value of explanatory variable. Gray shaded areas represent 95% Confidence Interval.

Full Dataset - Negative Binomial								
All Years Depth	All Years Shore	All Years Slope	All Years SST	All Years Desal	All Years Nutrients	**All Years Searching**	All Years Bottom	All Years Structure
								
1999-2009 Depth	1999-2009 Shore	1999-2009 Slope	1999-2009 SST	1999-2009 Desal	1999-2009 Nutrients	**1999-2009 Searching**	1999-2009 Bottom	1999-2009 Structure
								
2010-2019 Depth	2010-2019 Shore	2010-2019 Slope	2010-2019 SST	2010-2019 Desal	2010-2019 Nutrients	**2010-2019 Searching**	2010-2019 Bottom	2010-2019 Structure
								
Full Dataset - Tweedie								
All Years Depth	All Years Shore	All Years Slope	All Years SST	All Years Desal	All Years Nutrients	**All Years Searching**	All Years Bottom	All Years Structure
								
1999-2009 Depth	1999-2009 Shore	1999-2009 Slope	1999-2009 SST	1999-2009 Desal	1999-2009 Nutrients	**1999-2009 Searching**	1999-2009 Bottom	1999-2009 Structure
								
2010-2019 Depth	2010-2019 Shore	2010-2019 Slope	2010-2019 SST	2010-2019 Desal	2010-2019 Nutrients	**2010-2019 Searching**	2010-2019 Bottom	2010-2019 Structure
								

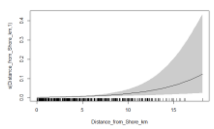
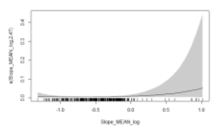
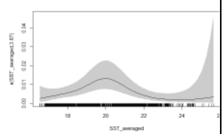
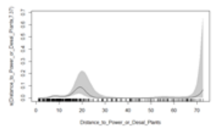
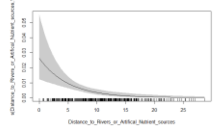
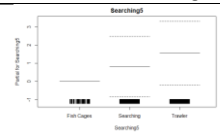
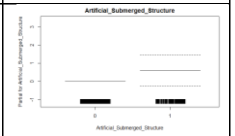
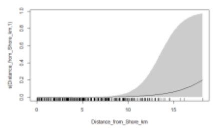
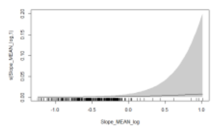
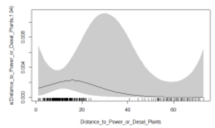
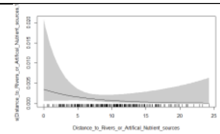
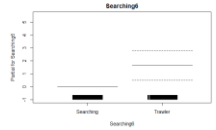
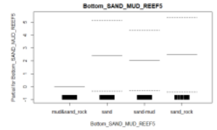
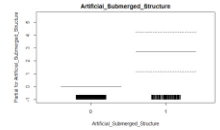
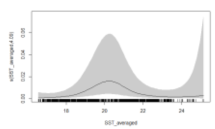
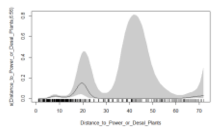
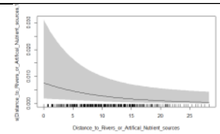
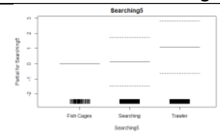
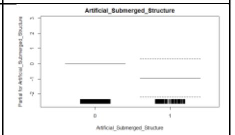
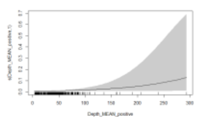
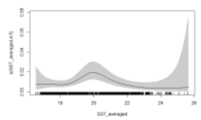
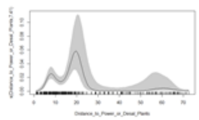
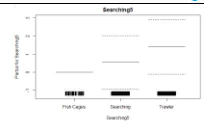
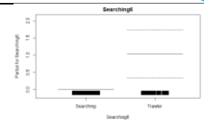
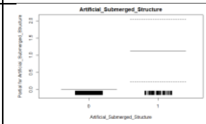
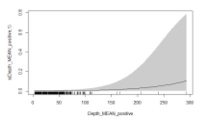
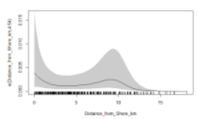
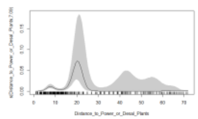
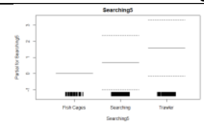
* Depth = Depth (m), Shore = Distance to Shore (km), Slope = log(Slope), SST = Sea Surface Temperature (°C), Desal = Distance to Desalination or Power Plants (km), Nutrients = Distance to Rivers or Artificial Nutrient Sources (km), Searching = Searching (randomized)/Trawler (in vicinity)/Fish Cages (in vicinity), Bottom = Type of substrate (mud/sand/rock), Structure = Artificial Submerged Structure (present/not present).

Table 7. Final models for *Tursiops truncatus* distribution, as run on the ‘Hot Season’ dataset for all years, years 1999-2009, and years 2010-2019. First three rows display results utilizing Negative Binomial distribution, while following three rows utilize Tweedie distribution. Variables that are statistically significant have names marked in blue. All vertical axes indicate the probability of dolphin occurrence on a scale of 0 to 1 (except instances where scale is minimized for clarity), while horizontal axes are presented in the units of the relevant explanatory variable, and above the horizontal axis are markings, indicating number of non-zero observations at that value of explanatory variable. Gray shaded areas represent 95% Confidence Interval.

Hot Season – Negative Binomial								
All Years Depth	All Years Shore	All Years Slope	All Years SST	All Years Desal	All Years Nutrients	**All Years Searching**	All Years Bottom	All Years Structure
								
1999-2009 Depth	1999-2009 Shore	1999-2009 Slope	1999-2009 SST	1999-2009 Desal	1999-2009 Nutrients	**1999-2009 Searching**	1999-2009 Bottom	1999-2009 Structure
								
2010-2019 Depth	2010-2019 Shore	2010-2019 Slope	2010-2019 SST	2010-2019 Desal	2010-2019 Nutrients	**2010-2019 Searching**	2010-2019 Bottom	2010-2019 Structure
								
Hot Season - Tweedie								
All Years Depth	All Years Shore	All Years Slope	All Years SST	All Years Desal	All Years Nutrients	**All Years Searching**	All Years Bottom	All Years Structure
								
1999-2009 Depth	1999-2009 Shore	1999-2009 Slope	1999-2009 SST	1999-2009 Desal	1999-2009 Nutrients	**1999-2009 Searching**	1999-2009 Bottom	1999-2009 Structure
								
2010-2019 Depth	2010-2019 Shore	2010-2019 Slope	2010-2019 SST	2010-2019 Desal	2010-2019 Nutrients	**2010-2019 Searching**	2010-2019 Bottom	2010-2019 Structure
								

* Depth = Depth (m), Shore = Distance to Shore (km), Slope = log(Slope), SST = Sea Surface Temperature (°C), Desal = Distance to Desalination or Power Plants (km), Nutrients = Distance to Rivers or Artificial Nutrient Sources (km), Searching = Searching (randomized)/Trawler (in vicinity)/Fish Cages (in vicinity), Bottom = Type of substrate (mud/sand/rock), Structure = Artificial Submerged Structure (present/not present).

Table 8. Final models for *Tursiops truncatus* distribution, as run on the 'Cold Season' dataset for all years, years 1999-2009, and years 2010-2019. First three rows display results utilizing Negative Binomial distribution, while following three rows utilize Tweedie distribution. Variables that are statistically significant have names marked in blue. All vertical axes indicate the probability of dolphin occurrence on a scale of 0 to 1 (except instances where scale is minimized for clarity), while horizontal axes are presented in the units of the relevant explanatory variable, and above the horizontal axis are markings, indicating number of non-zero observations at that value of explanatory variable. Gray shaded areas represent 95% Confidence Interval.

Cold Season – Negative Binomial								
All Years Depth	All Years Shore	All Years Slope	All Years SST	All Years Desal	All Years Nutrients	**All Years Searching**	All Years Bottom	All Years Structure
								
1999-2009 Depth	1999-2009 Shore	1999-2009 Slope	1999-2009 SST	1999-2009 Desal	1999-2009 Nutrients	**1999-2009 Searching**	1999-2009 Bottom	1999-2009 Structure
								
2010-2019 Depth	2010-2019 Shore	2010-2019 Slope	2010-2019 SST	2010-2019 Desal	2010-2019 Nutrients	**2010-2019 Searching**	2010-2019 Bottom	2010-2019 Structure
								
Cold Season - Tweedie								
All Years Depth	All Years Shore	All Years Slope	All Years SST	All Years Desal	All Years Nutrients	**All Years Searching**	All Years Bottom	All Years Structure
								
1999-2009 Depth	1999-2009 Shore	1999-2009 Slope	1999-2009 SST	1999-2009 Desal	1999-2009 Nutrients	**1999-2009 Searching**	1999-2009 Bottom	1999-2009 Structure
								
2010-2019 Depth	2010-2019 Shore	2010-2019 Slope	2010-2019 SST	2010-2019 Desal	2010-2019 Nutrients	**2010-2019 Searching**	2010-2019 Bottom	2010-2019 Structure
								

* Depth = Depth (m), Shore = Distance to Shore (km), Slope = log(Slope), SST = Sea Surface Temperature (°C), Desal = Distance to Desalination or Power Plants (km), Nutrients = Distance to Rivers or Artificial Nutrient Sources (km), Searching = Searching (randomized)/Trawler (in vicinity)/Fish Cages (in vicinity), Bottom = Type of substrate (mud/sand/rock), Structure = Artificial Submerged Structure (present/not present).

Spatial Models - Areas 1 / 2 / 3 / 4 / 5

Area 1

Negative Binomial - In ‘Area 1’, the only variable that was significant was ‘Searching’ during both the ‘All Years’ model, and the ‘1999-2009’ model, but not during the ‘2010-2019’ models. This lack of significant results indicates that this section of the Israeli coast did not have sufficient survey coverage to determine *T. truncatus* habitat preferences through modeling. The ‘Searching’ variable presents higher probability of dolphin occurrence in the presence of a trawler when compared to open water. Furthermore, in this area of the Israeli coast there has been a ban on trawling since 2016, and a marine protected area (no fishing zone) established to protect the unique underwater canyon in that region. ‘Area 1’ includes only 13 sightings across the entire survey period, all of these occurring between 2007 – 2013, though survey effort has continued in the years 2013, but in slightly lower quantity (Table 9).

Tweedie – In ‘Area 1’ the variable ‘Distance to Desal or Power Plants’ was significant during both the ‘All Years’ model and the ‘2010-2019’ model, though the high uncertainty that envelopes the majority of both plots makes results difficult to interpret. During the ‘2010-2019’ model, ‘Searching’ is also a significant variable, and the plot displays higher probability of occurrence in the vicinity of trawlers. The only variable that was significant during the ‘1999-2009’ model was ‘Slope’, which presented overall low probability of occurrence that increased only when log(slope) was greater than 0.5, though this was matched with an increase in uncertainty (Table 9).

Area 2

Negative Binomial / Tweedie - ‘Area 2’ was not possible to model at all since only 1 *T. truncatus* sighting occurred in this area across the whole study period (Table 9).

Area 3

Negative Binomial - ‘Area 3’ presented no significant variables for the ‘1999-2009’ model or the ‘2010-2019’ model. However, the ‘All Years’ model presented all significant variables; ‘Distance to Desal or Power Plants’, ‘Depth’, ‘Distance to Artificial Nutrient Sources’, ‘Searching’ and ‘Bottom Content’. The ‘Distance to Desal or Power Plants’ plot displayed low probability of dolphin occurrence and low uncertainty up until a distance of 40 km, where uncertainty greatly increased due to lack of observations. The ‘Depth’ plot displayed decreasing probability of dolphin occurrence, with large uncertainty up to a depth of 10 km, followed by consistent, low probability of occurrence and low uncertainty. The ‘Distance to Rivers or Artificial Nutrient Sources’ plot presented low probability of dolphin occurrence up to a distance of 10 km, after which probability increased, but also uncertainty. The ‘Searching’ plot displayed higher probability of dolphin occurrence in the vicinity of trawlers, and the ‘Bottom Content’ plot displayed difference in probability of dolphin occurrence between the different habitat and sediment types, in particular, probability of dolphin occurrence was lower and more variable in areas where the seafloor was composed of ‘sand and rock’, in comparison to areas composed of ‘sand only’, ‘sand and mud’, or ‘sand, mud and rock’ (Table 9).

Tweedie – In ‘Area 3’ the ‘Searching’ variable was significant during the ‘All Years’ model and the ‘1999-2009’ model, with both plots displaying higher probability of occurrence in the vicinity of trawlers and the

‘1999-2009’ model also displaying elevated probability of occurrence in the vicinity of fish cages. Additional significant variables included ‘Distance to Desal or Power Plants’ during the ‘All Years’ model which presented low probability of occurrence and high uncertainty, ‘Depth’ during the ‘1999-2009’ model, which presented a decline in probability of occurrence at approximately 30m depth. Lastly, ‘Slope’ was significant during the ‘2010-2019’ model, though this variable displayed overall low probability of dolphin occurrence (Table 9).

Area 4

Negative Binomial - In ‘Area 4’, the variables ‘Sea Surface Temperature’ and ‘Searching’ were significant across all three models. Although the variability in the ‘Sea Surface Temperature’ plots were difficult to interpret and likely overfitted the data, the ‘Searching’ plots all showed very clearly that dolphins presented higher occurrence in the vicinity of trawlers. In the ‘1999-2009’ model, ‘Distance to Artificial Nutrient Sources’ was also significant and presented a decreasing trend in dolphin occurrence as distance increase. During the ‘2010-2019’ model, ‘Distance from Shore’ was also significant, and the plot presented low and somewhat variable probability of dolphin occurrence across most of the plot (Table 9).

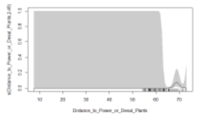
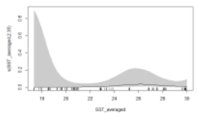
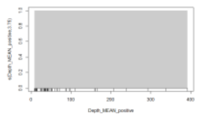
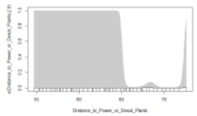
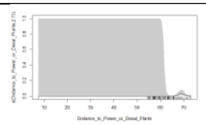
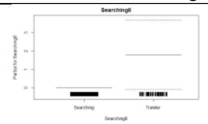
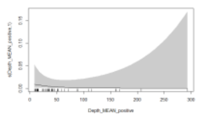
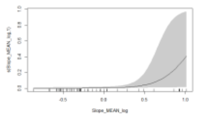
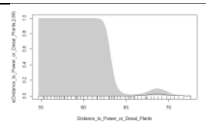
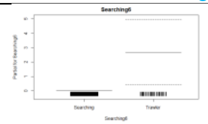
Tweedie - In ‘Area 4’, the variable ‘Searching’ was significant across all three models, and in all three plots displayed higher probability of occurrence in the vicinity of trawlers. The ‘Sea Surface Temperature’ variable was also significant during the ‘All Years’ model and presented peaks in probability of dolphin occurrence at approximately 20°C and 28°C. The ‘Distance to Desal or Power Plants’ variable was significant during the ‘2010-2019’ model and displayed over low probability of occurrence (Table 9).

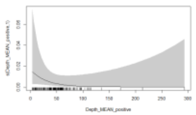
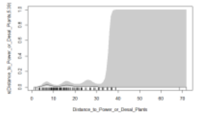
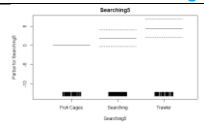
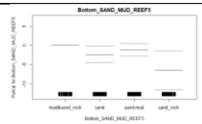
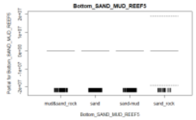
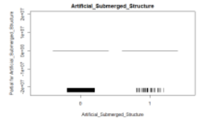
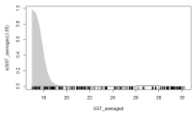
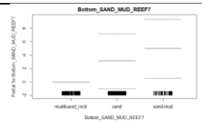
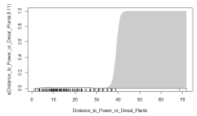
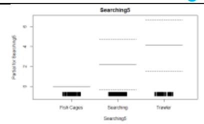
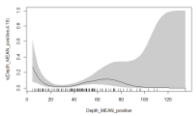
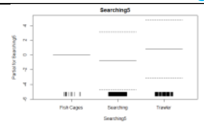
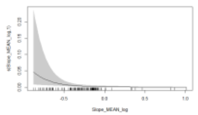
Area 5

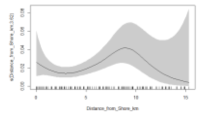
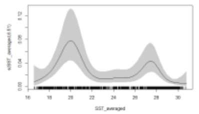
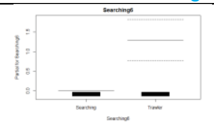
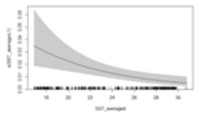
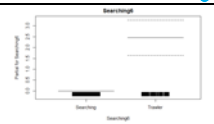
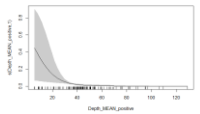
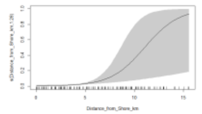
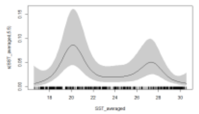
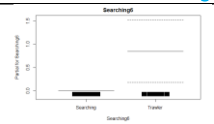
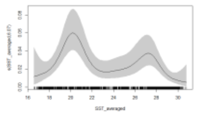
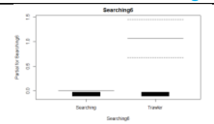
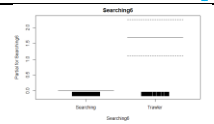
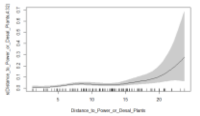
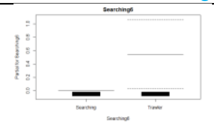
Negative Binomial – ‘Area 5’ presented very few significant variables, with ‘Depth’ being significant in the ‘All Years’ model and displaying an increasing trend in probability of dolphin occurrence as depth increases, though this trend is matched with an increase in uncertainty. Additionally, ‘Searching’ was significant in the ‘2010-2019’ model and displayed higher dolphin occurrence in the vicinity of fish cages (Table 9).

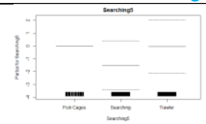
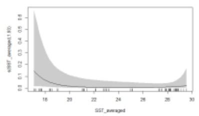
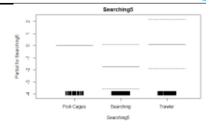
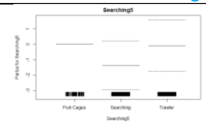
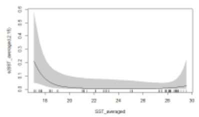
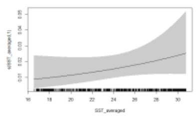
Tweedie – ‘Area 5’ only presented two significant variables- ‘Searching’ during the ‘All Years’ model a ‘Sea Surface Temperature’ during the ‘1999-2009’ model. Considering the low survey coverage between the years 1999-2009, these results are indicative of insufficient data in this area for statistical modeling (Table 9).

Table 9. Final models for *Tursiops truncatus* distribution, as run on the spatial subsets (Areas 1/2/3/4/5) for all years, years 1999-2009, and years 2010-2019. First three rows in each section displays results utilizing Negative Binomial distribution, while following three rows utilize Tweedie distribution. Variables that are statistically significant have names marked in blue. All vertical axes indicate the probability of dolphin occurrence on a scale of 0 to 1 (except instances where scale is minimized for clarity), while horizontal axes are presented in the units of the relevant explanatory variable, and above the horizontal axis are markings, indicating number of non-zero observations at that value of explanatory variable. Gray shaded areas represent 95% Confidence Interval.

Area 1 – Negative Binomial								
All Years Depth	All Years Shore	All Years Slope	All Years SST	All Years Desal	All Years Nutrients	**All Years Searching**	All Years Bottom	All Years Structure
								
1999-2009 Depth	1999-2009 Shore	1999-2009 Slope	1999-2009 SST	1999-2009 Desal	1999-2009 Nutrients	**1999-2009 Searching**	1999-2009 Bottom	1999-2009 Structure
								
2010-2019 Depth	2010-2019 Shore	2010-2019 Slope	2010-2019 SST	2010-2019 Desal	2010-2019 Nutrients	**2010-2019 Searching**	2010-2019 Bottom	2010-2019 Structure
								
Area 1 - Tweedie								
All Years Depth	All Years Shore	All Years Slope	All Years SST	All Years Desal	All Years Nutrients	**All Years Searching**	All Years Bottom	All Years Structure
								
1999-2009 Depth	1999-2009 Shore	1999-2009 Slope	1999-2009 SST	1999-2009 Desal	1999-2009 Nutrients	**1999-2009 Searching**	1999-2009 Bottom	1999-2009 Structure
								
2010-2019 Depth	2010-2019 Shore	2010-2019 Slope	2010-2019 SST	2010-2019 Desal	2010-2019 Nutrients	**2010-2019 Searching**	2010-2019 Bottom	2010-2019 Structure
								

Area 3 – Negative Binomial								
All Years Depth	All Years Shore	All Years Slope	All Years SST	All Years Desal	All Years Nutrients	**All Years Searching**	All Years Bottom	All Years Structure
								
1999-2009 Depth	1999-2009 Shore	1999-2009 Slope	1999-2009 SST	1999-2009 Desal	1999-2009 Nutrients	**1999-2009 Searching**	1999-2009 Bottom	1999-2009 Structure
								
2010-2019 Depth	2010-2019 Shore	2010-2019 Slope	2010-2019 SST	2010-2019 Desal	2010-2019 Nutrients	**2010-2019 Searching**	2010-2019 Bottom	2010-2019 Structure
								
Area 3 - Tweedie								
All Years Depth	All Years Shore	All Years Slope	All Years SST	All Years Desal	All Years Nutrients	**All Years Searching**	All Years Bottom	All Years Structure
								
1999-2009 Depth	1999-2009 Shore	1999-2009 Slope	1999-2009 SST	1999-2009 Desal	1999-2009 Nutrients	**1999-2009 Searching**	1999-2009 Bottom	1999-2009 Structure
								
2010-2019 Depth	2010-2019 Shore	2010-2019 Slope	2010-2019 SST	2010-2019 Desal	2010-2019 Nutrients	**2010-2019 Searching**	2010-2019 Bottom	2010-2019 Structure
								

Area 4 – Negative Binomial								
All Years Depth	All Years Shore	All Years Slope	All Years SST	All Years Desal	All Years Nutrients	**All Years Searching**	All Years Bottom	All Years Structure
								
1999-2009 Depth	1999-2009 Shore	1999-2009 Slope	1999-2009 SST	1999-2009 Desal	1999-2009 Nutrients	**1999-2009 Searching**	1999-2009 Bottom	1999-2009 Structure
								
2010-2019 Depth	2010-2019 Shore	2010-2019 Slope	2010-2019 SST	2010-2019 Desal	2010-2019 Nutrients	**2010-2019 Searching**	2010-2019 Bottom	2010-2019 Structure
								
Area 4 - Tweedie								
All Years Depth	All Years Shore	All Years Slope	All Years SST	All Years Desal	All Years Nutrients	**All Years Searching**	All Years Bottom	All Years Structure
								
1999-2009 Depth	1999-2009 Shore	1999-2009 Slope	1999-2009 SST	1999-2009 Desal	1999-2009 Nutrients	**1999-2009 Searching**	1999-2009 Bottom	1999-2009 Structure
								
2010-2019 Depth	2010-2019 Shore	2010-2019 Slope	2010-2019 SST	2010-2019 Desal	2010-2019 Nutrients	**2010-2019 Searching**	2010-2019 Bottom	2010-2019 Structure
								

Area 5 - Negative Binomial								
All Years Depth	All Years Shore	All Years Slope	All Years SST	All Years Desal	All Years Nutrients	**All Years Searching**	All Years Bottom	All Years Structure
								
1999-2009 Depth	1999-2009 Shore	1999-2009 Slope	1999-2009 SST	1999-2009 Desal	1999-2009 Nutrients	**1999-2009 Searching**	1999-2009 Bottom	1999-2009 Structure
								
2010-2019 Depth	2010-2019 Shore	2010-2019 Slope	2010-2019 SST	2010-2019 Desal	2010-2019 Nutrients	**2010-2019 Searching**	2010-2019 Bottom	2010-2019 Structure
								
Area 5 - Tweedie								
All Years Depth	All Years Shore	All Years Slope	All Years SST	All Years Desal	All Years Nutrients	**All Years Searching**	All Years Bottom	All Years Structure
								
1999-2009 Depth	1999-2009 Shore	1999-2009 Slope	1999-2009 SST	1999-2009 Desal	1999-2009 Nutrients	**1999-2009 Searching**	1999-2009 Bottom	1999-2009 Structure
								
2010-2019 Depth	2010-2019 Shore	2010-2019 Slope	2010-2019 SST	2010-2019 Desal	2010-2019 Nutrients	**2010-2019 Searching**	2010-2019 Bottom	2010-2019 Structure
								

* Depth = Depth (m), Shore = Distance to Shore (km), Slope = log(Slope), SST = Sea Surface Temperature (°C), Desal = Distance to Desalination or Power Plants (km), Nutrients = Distance to Rivers or Artificial Nutrient Sources (km), Searching = Searching (randomized)/Trawler (in vicinity)/Fish Cages (in vicinity), Bottom = Type of substrate (mud/sand/rock), Structure = Artificial Submerged Structure (present/not present).

3.3.2 Trawler Excluded Models

In order to differentiate between dolphin habitat use affected by man-made food sources such as trawlers and fish cages, from natural dolphin habitat use, all sightings related to either trawlers or fish cages were removed from the dataset, and models were created for 'Trawler Excluded' data in Areas 3, 4, and 5. Four final models were constructed by use of stepwise model selection: 'Area 3', 'Area 4', 'Area 5', and 'Areas 3, 4 & 5'.

The 'Trawler Excluded' models utilizing Negative Binomial distribution presented 'deviance explained' values that varied between 14% and 33%, while number of explanatory variables were either 3 or 4 (Table 10). Of the 4 models, the explanatory variables that were retained in the highest number of models were 'Depth' (4 models), 'Distance to Desal or Power Plants' (3 models), 'SST' (2 models), 'Distance to Rivers or Artificial Nutrient Sources' (2 models), 'Bottom Content' (2 models), and 'Submerged Structures' (1 models).

The 'Trawler Excluded' models utilizing Tweedie distribution presented 'deviance explained' values that varied between 2% and 19%, while number of explanatory variables ranged from 1 to 4 (Table 10). Of the 4 models, the explanatory variables that were retained in the highest number of models were 'Distance to Shore' (2 models), 'Distance to Desal or Power Plants' (2 models), 'SST' (2 models), 'Distance to Rivers or Artificial Nutrient Sources' (1 models), and 'Depth' (1 model).

Area 3, 4 & 5 – Trawler Excluded

Negative Binomial - The explanatory variables retained in model 'Area 3, 4 & 5 – Trawler Excluded' following model selection were 'Depth', 'Distance to Desal or Power Plants', 'Sea Surface Temperature' and 'Artificial Submerged Structures'. Of these four, only 'Depth' and 'Distance to Desal or Power Plants' were statistically significant. The plot for 'Depth' displayed a small peak in probability of dolphin occurrence around a depth of 50 m, and a high uncertainty from a depth of 100m and onwards. The plot for 'Distance to Desal or Power Plants' displayed overall low probability of dolphin occurrence, and a high uncertainty from 40 km and onwards (Table 11).

Tweedie – Similarly to the Negative Binomial models, the explanatory variables retained in model 'Area 3, 4 & 5 – Trawler Excluded' following model selection were 'Depth', 'Distance to Desal or Power Plants' and 'Sea Surface Temperature' though unlike the Negative Binomial models, 'Distance to Shore' was also retained. All except for 'Depth' were significant, and both 'Distance to Shore' and 'Distance to Desal or Power Plants' displayed over low probability of occurrence, while 'Sea Surface Temperature' displayed two peaks in occurrence, around 20°C and 28°C (Table 11).

Area 3 – Trawler Excluded

Negative Binomial - The explanatory variables retained in model 'Area 3 – Trawler Excluded' following model selection were 'Depth', 'Distance to Desal or Power Plants', and 'Bottom Content'. None of these three were statistically significant. The plots for 'Depth' and 'Distance to Desal or Power Plants' display high uncertainty across the entire plot. It is apparent that the searching data from 'Area 3' alone is not sufficient for informative results (Table 11).

Tweedie – The only explanatory variable retained in model 'Area 3 – Trawler Excluded' following model selection was 'Distance to Shore', which displayed a gradual increase in probability of occurrence as slope increased (Table 11).

Area 4 – Trawler Excluded

Negative Binomial - The explanatory variables retained in model 'Area 4 – Trawler Excluded' following model selection were 'Depth', 'Sea Surface Temperature' and 'Bottom Content'. All three of these variables were statistically significant. The plot for 'Depth' displayed decreasing dolphin occurrence as depth increased, with a high uncertainty up to a depth of 30 m. The plot for 'Sea Surface Temperature' displayed a peak in dolphin occurrence around 20° C, though the overall trend in the plot appears to display overfitting of the data. The plot for 'Bottom Content' presents higher dolphin occurrence in areas where the substrate is composed of 'mud, sand and rock', or 'mud and sand', when compared to areas of 'sand only' or 'sand and rock' (Table 11).

Tweedie - The only explanatory variable retained in model 'Area 4 – Trawler Excluded' following model selection was 'Distance to Desal or Power Plants', which displayed an increase in probability of occurrence at distances greater than 30 km, although this increase was also matched with an increase in uncertainty (Table 11).

Area 5 – Trawler Excluded

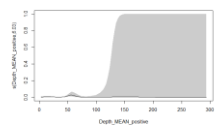
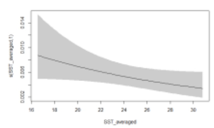
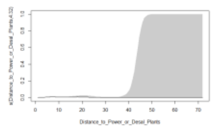
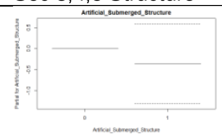
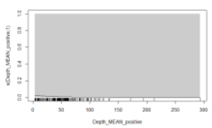
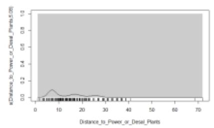
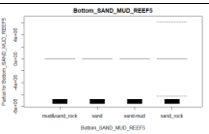
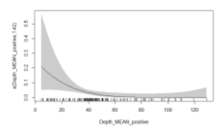
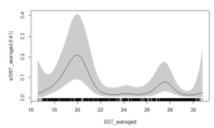
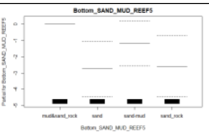
Negative Binomial - The explanatory variables retained in model 'Area 5 – Trawler Excluded' following model selection were 'Depth', 'Distance to Desal or Power Plants', 'Distance to Rivers or Artificial Nutrient Sources' and 'Sea Surface Temperature'. Of these four variables, only 'Depth' and 'Distance to Desal or Power Plants' were statistically significant. The plot for 'Depth' displayed increasing probability of dolphin occurrence as depth increased, though this trend was matched with high uncertainty from 80 m and onwards. The plot for 'Distance to Desal or Power Plants' displayed decreasing probability of dolphin occurrence as distance increased, as well as high uncertainty up to a distance of 5 km (Table 11).

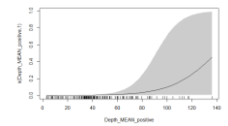
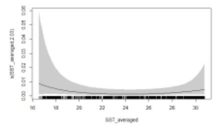
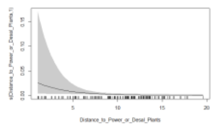
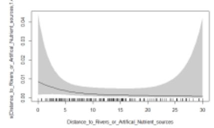
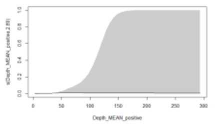
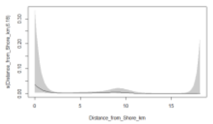
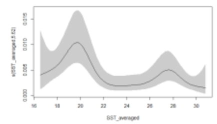
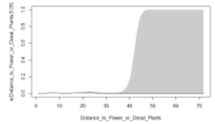
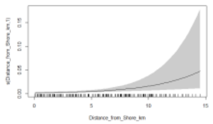
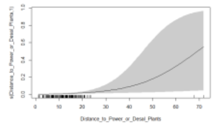
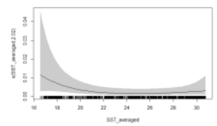
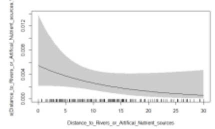
Tweedie - The explanatory variables retained in model 'Area 5 – Trawler Excluded' following model selection were 'Sea Surface Temperature' and 'Distance to Rivers or Artificial Nutrients Sources', though neither were statistically significant (Table 11).

Table 10. Summary of 'search-only' models for each spatial section. Information includes number of sightings within the subset, number of zero values, deviance explained for both Negative Binomial and Tweedie models, and names of explanatory variables for both Negative Binomial and Tweedie models.

Model name	Searching Dolphin Observations	Searching Zero	Trawler Dolphin Observations	Trawler Zero	Fish Cages Dolphin Observations	Fish Cages Zero	% Deviance Explained (NB)	Variable names (NB)	% Deviance Explained (TW)	Variable names (TW)
Sec 3 & 4 & 5, All Years	125	15715	139	3494	6	786	13	DEPTH + DESAL + SST + WRECK	19	DEPTH + SHORE + DESAL + SST
Sec 3, All Years	25	3491	17	366	1	489	33	DESAL + BOTTOM + DEPTH	9	SHORE
Sec 4, All Years	76	7502	96	2119	0	0	21	SST + DEPTH + BOTTOM	2	DESAL
Sec 5, All Years	24	4722	26	1009	5	297	14	NUTRIENTS + DEPTH + DESAL + SST	9	NUTRIENTS + SST

Table 11. Final models for *Tursiops truncatus* distribution, as run on the searching-only dataset (Areas 3&4&5/3/4/5) for all years, years 1999-2009, and years 2010-2019. Results utilizing Negative Binomial distribution are displayed, followed by results utilizing Tweedie distribution. Variables that are statistically significant have names marked in blue. All vertical axes indicate the probability of dolphin occurrence on a scale of 0 to 1 (except instances where scale is minimized for clarity), while horizontal axes are presented in the units of the relevant explanatory variable, and above the horizontal axis are markings, indicating number of non-zero observations at that value of explanatory variable. Gray shaded areas represent 95% Confidence Interval.

Trawler Excluded – Negative Binomial							
Sec 3,4,5 Depth	Sec 3,4,5 Shore	Sec 3,4,5 Slope	Sec 3,4,5 SST	Sec 3,4,5 Desal	Sec 3,4,5 Nutrients	Sec 3,4,5 Bottom	Sec 3,4,5 Structure
							
Sec 3 Depth	Sec 3 Shore	Sec 3 Slope	Sec 3 SST	Sec 3 Desal	Sec 3 Nutrients	Sec 3 Bottom	Sec 3 Structure
							
Sec 4 Depth	Sec 4 Shore	Sec 4 Slope	Sec 4 SST	Sec 4 Desal	Sec 4 Nutrients	Sec 4 Bottom	Sec 4 Structure
							
Sec 5 Depth	Sec 5 Shore	Sec 5 Slope	Sec 5 SST	Sec 5 Desal	Sec 5 Nutrients	Sec 5 Bottom	Sec 5 Structure

							
Trawler Excluded - Tweedie							
Sec 3,4,5 Depth	Sec 3,4,5 Shore	Sec 3,4,5 Slope	Sec 3,4,5 SST	Sec 3,4,5 Desal	Sec 3,4,5 Nutrients	Sec 3,4,5 Bottom	Sec 3,4,5 Structure
							
Sec 3 Depth	Sec 3 Shore	Sec 3 Slope	Sec 3 SST	Sec 3 Desal	Sec 3 Nutrients	Sec 3 Bottom	Sec 3 Structure
							
Sec 4 Depth	Sec 4 Shore	Sec 4 Slope	Sec 4 SST	Sec 4 Desal	Sec 4 Nutrients	Sec 4 Bottom	Sec 4 Structure
							
Sec 5 Depth	Sec 5 Shore	Sec 5 Slope	Sec 5 SST	Sec 5 Desal	Sec 5 Nutrients	Sec 5 Bottom	Sec 5 Structure
							

* Depth = Depth (m), Shore = Distance to Shore (km), Slope = log(Slope), SST = Sea Surface Temperature (°C), Desal = Distance to Desalination or Power Plants (km), Nutrients = Distance to Rivers or Artificial Nutrient Sources (km), Searching = Searching (randomized)/Trawler (in vicinity)/Fish Cages (in vicinity), Bottom = Type of substrate (mud/sand/rock), Structure = Artificial Submerged Structure (present/not present).

Prediction Maps – Trawler excluded

Based on the final 'Trawler Excluded' models utilizing Negative Binomial distribution from sections 4, 5 and 3, 4 & 5 combined, as well the 'Trawler Excluded' model utilizing the Tweedie distribution from Area 3, 4 & 5 combined, prediction maps were created. These maps display the probability of occurrence for *T. truncatus* along the Israeli continental shelf. The maps show that certain explanatory variables had stronger effects on the final prediction, such as 'Depth' (Figure 15A, 15B, 15C) or 'Distance to Desal or Power Plants' (Figure 15D). The maps also display an overall similarity when comparing between predictions utilizing Negative Binomial distribution or Tweedie distribution based on Areas 3, 4 & 5 (Figure 15A, 15B).

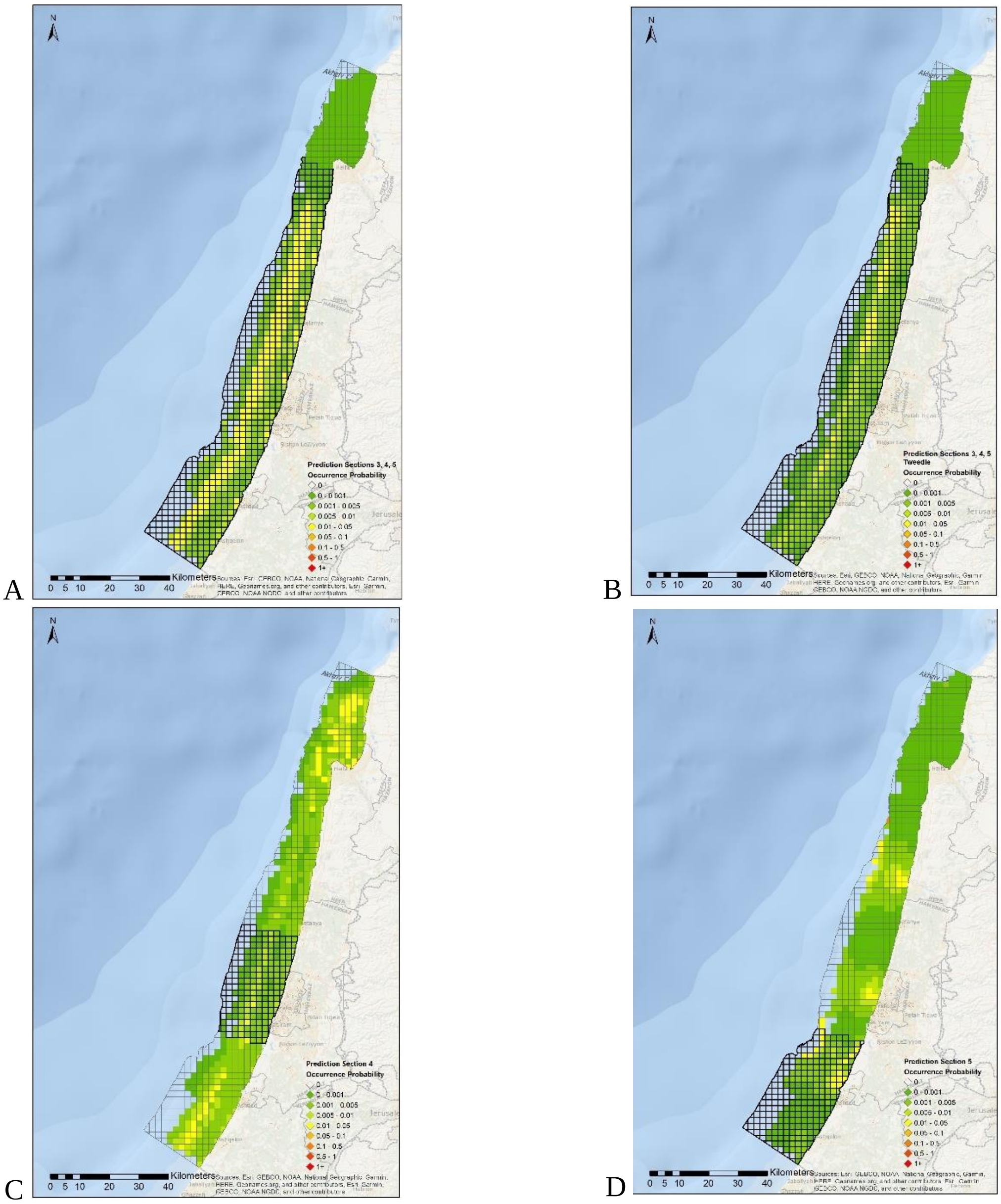


Figure 15. A) Prediction Map for *Tursiops truncatus* based on Negative Binomial distribution and 'trawler excluded' data from Areas 3, 4, and 5. B) Prediction Map for *Tursiops truncatus* based on Tweedie distribution and 'trawler excluded' data from Areas 3, 4, and 5. C) Prediction Map for *Tursiops truncatus* based on Negative Binomial distribution and 'trawler excluded' data from 'Area 4'. D) Prediction Map for *Tursiops truncatus* based on Negative Binomial distribution and "trawler excluded" data from 'Area 5'.

3.3.3 Non – Correlated Data Models

In an attempt to narrow down the dataset to the most meaningful part of the data, four models were constructed, utilizing only the data that was retained after performing the Spearman's Rank Correlation Test prior to the creation of occurrence maps (Section 2.6). The four models constructed from portion of the dataset: 1) 1999-2009, 2) 2010-2019, 3) Hot Season, and 4) Cold Season.

The 'Non-Correlated Data' models based on Negative Binomial distribution presented deviance explained values that varied between 12% and 23%, while number of explanatory variables were either 3 or 5 (Table 12). Of the 4 models, the explanatory variables that were retained in the highest number of models were 'Searching' (4 models), 'Sea Surface Temperature' (3 models), 'Distance to Desal or Power Plants' (2 models), 'Distance from Shore' (2 models), 'Depth' (1 model), 'Slope' (1 model), and 'Bottom Content' (1 model).

The 'Non-Correlated Data' models based on Tweedie distribution presented deviance explained values that varied between 8% and 21%, while number of explanatory variables were either 1 or 3 (Table 12). Of the 4 models, the explanatory variables that were retained in the highest number of models were 'Searching' (4 models), 'Distance to Desal or Power Plants' (2 models), 'Sea Surface Temperature' (2 models), 'Distance to Rivers or Artificial Nutrients Sources' (1 model), and 'Slope' (1 model).

1999-2009 – Non-Correlated Data

Negative Binomial - The explanatory variables retained in model '1999-2009 - Non-Correlated Data' following model selection were 'Distance from Shore', 'Slope', and 'Searching'. Of these three, 'Distance from Shore' and 'Searching' were statistically significant. The plot for 'Distance to Shore' displays an increasing trend in probability of dolphin occurrence as distance increases. The plot for 'Searching' clearly shows that dolphin occurrence is higher when there are trawlers in the vicinity (Table 13).

Tweedie - The only explanatory variable retained in model '1999-2009 – Non-Correlated Data' following model selection was 'Searching', which demonstrated higher probability of occurrence in the vicinity of trawlers and fishcages (Table 13).

2010-2019 – Non-Correlated Data

Negative Binomial - The explanatory variables retained in model '2010-2019 - Non-Correlated Data' following model selection were 'Distance to Desal or Power Plants', 'Sea Surface Temperature', and 'Searching'. All three of these variables were statistically significant. The plot for 'Distance to Desal or Power Plants' displays an increasing trend in probability of dolphin occurrence, up to a distance of 10 km, followed by a decrease and high uncertainty. The plot for 'Searching' clearly shows that dolphin occurrence is higher when there are trawlers in the vicinity (Table 13).

Tweedie – Similarly to the Negative Binomial models, the explanatory variables retained in model '2010-2019 - Non-Correlated Data' following model selection were 'Distance to Desal or Power Plants', 'Sea Surface Temperature', and 'Searching', with all three being statistically significant (Table 13).

Hot Season – Non-Correlated Data

Negative Binomial - The explanatory variables retained in model 'Hot Season - Non-Correlated Data' following model selection were 'Distance to Power or Desal Plants', 'Searching', 'Distance from Shore', 'Sea Surface Temperature', and 'Bottom Content'. Of these five variables, all but 'Distance to Shore' were statistically significant. The plot for 'Distance from Shore' displayed overall low probability of dolphin occurrence, with a decreasing trend as distance increases, as did the plot for 'Distance to Power or Desal Plants', though some differences can be observed across the 95% CI. The plot for 'Sea Surface Temperature' also displayed low probability, with a small peak at approximately 28°C. The plot for 'Searching' clearly shows that dolphin occurrence is higher when there are trawlers in the vicinity, while the plot for 'Bottom Content' presents higher probability of occurrence in areas consisting of sand, mud and rock combined (Table 13).

Tweedie - The explanatory variables retained in model 'Hot Season - Non-Correlated Data' following model selection were 'Slope', 'Sea Surface Temperature', and 'Searching', of which only 'Sea Surface Temperature' was statistically significant. The plot for 'Slope' displayed a slight increase in probability of dolphin occurrence and also uncertainty as slope increased, though overall probability of occurrence was low across the plot. The plot for 'Sea Surface Temperature' also displayed overall low probability of occurrence, with a small peak at approximately 28°C. Lastly, the plot for 'Searching' displayed slightly higher probability of occurrence during open-water search and in the vicinity of trawlers, when compared with searching in the vicinity of fish cages (Table 13).

Cold Season – Non-Correlated Data

Negative Binomial - The explanatory variables retained in model 'Cold Season - Non-Correlated Data' following model selection were 'Depth', 'Sea Surface Temperature', and 'Searching'. All three variables were statistically significant, though the plots for 'Depth' and 'Sea Surface Temperature' were overridden with uncertainty and therefore uninterpretable. Additionally, the plot for 'Searching', although significant, did not display differences between surveying in open water, in vicinity of fish cages and in the vicinity of trawlers (Table 13).

Tweedie - The explanatory variables retained in model 'Cold Season - Non-Correlated Data' following model selection were 'Distance to Desal or Power Plants', 'Distance to Power or Desal Plants' and 'Searching'. 'Distance to Desal or Power Plants' and 'Searching' were both statistically significant. 'Distance to Desal or Power Plants' displayed overall low probability of occurrence with a slight peak at a distance of 8 km, while 'Searching' displayed higher probability of occurrence in the vicinity of trawlers (Table 13).

3.3.4 Non-Correlated Data, Trawler Excluded Models

In an attempt to better define the environmental variables influencing *T. truncatus* spatial distribution and occurrence, four additional models were constructed utilizing the data that was retained after performing the Spearman's Rank Correlation Test, following removal of all sightings and survey effort related to trawlers. Similarly to the 'Non-Correlated' dataset, the models constructed were; 1) 1999-2009, 2) 2010-2019, 3) Hot Season, and 4) Cold Season.

The 'Non-Correlated Data, Trawler Excluded' models based on Negative Binomial distribution presented 'deviance explained' values that varied between 14% and 34%, while number of explanatory variables was either 4 or 5 (Table 12). Of the 4 models, the explanatory variables that were retained in the highest number of models were 'Depth' (4 models), 'Sea Surface Temperature' (3 models), 'Distance to Desal or Power Plants' (3 models), 'Bottom Content' (3 models), 'Distance from Shore' (1 models), 'Distance to Rivers or Artificial Nutrient Sources' (1 model), 'Slope' (1 model), and 'Submerged Structures' (1 model).

The 'Non-Correlated Data, Trawler Excluded' models based on Tweedie distribution presented 'deviance explained' values that varied between 5% and 15%, while number of explanatory variables were either 1 or 2 (Table 12). Of the 4 models, the explanatory variables that were retained in the highest number of models were 'Distance to Desal or Power Plants' (3 models), 'Sea Surface Temperature' (2 models), and 'Depth' (2 models).

1999-2009 – Non-Correlated Data, Trawler Excluded

Negative Binomial - The explanatory variables retained in model '1999-2009 - Non-Correlated Data, Trawler Excluded' following model selection were 'Distance to Desal or Power Plant', 'Depth', 'Sea Surface Temperature' and 'Bottom Content'. Of these four, 'Distance to Desal or Power Plant', 'Sea Surface Temperature' and 'Bottom Content' were statistically significant. The plot for 'Distance to Desal or Power Plant' displays a decreasing trend in probability of dolphin occurrence as distance increases. The plot for 'Sea Surface Temperature' also displays a decreasing trend in dolphin occurrence as temperature increases. The plot for 'Bottom Content' presents higher dolphin occurrence for the sediment type 'mud, sand and rock' compared to other sediment types (Table 14).

Tweedie - The only explanatory variable retained in model '1999-2009 - Non-Correlated Data, Trawler Excluded' following model selection was 'Sea Surface Temperature' which presented a decline in probability of dolphin occurrence across the entire plot, as temperature increased (Table 14).

2010-2019 – Non-Correlated Data, Trawler Excluded

Negative Binomial - The explanatory variables retained in model '2010-2019 - Non-Correlated Data, Trawler Excluded' following model selection were 'Distance to Desal or Power Plant', 'Distance from Shore', 'Depth', and 'Sea Surface Temperature'. All four of these variables were statistically significant. The plot for 'Distance to Desal or Power Plant' displays a decreasing trend in dolphin occurrence as distance increases. The plot for 'Distance from Shore' displays a sharp decline in probability of dolphin occurrence up to a distance of 1 km, after which, probability of occurrence is generally low. The plot for 'Depth' presents 2 peaks in probability of dolphin occurrence, the first small peak occurs at approximately 50 m depth and the second larger pear occurs at approx. 200 m depth, though the second peak is based on only 1 sighting and is matched with high uncertainty that fills the entire plot. The plot for 'Sea Surface Temperature' is variable and presents 2 peaks in probability of dolphin occurrence, at 20° and 28° C, though both are matched with high uncertainty (Table 14).

Tweedie - The explanatory variables retained in model '2010-2019 - Non-Correlated Data, Trawler Excluded' following model selection were 'Depth' and 'Distance to Desal or Power Plant', of which only the latter was statistically significant, and presented a peak in probability of occurrence at a distance of approximately 8km (Table 14).

Hot Season – Non-Correlated Data, Trawler Excluded

Negative Binomial - The explanatory variables retained in model 'Hot Season - Non-Correlated Data, Trawler Excluded' following model selection were 'Depth', 'Slope', 'Distance to Desal or Power Plant', 'Sea Surface Temperature', and 'Bottom Content'. Of these five variables, 'Slope', 'Distance to Desal or Power Plant', and 'Bottom Content' were statistically significant. The plot for 'Distance from Shore' displayed a continuously decreasing trend in probability of occurrence as distance increased. The plots for 'Depth', 'Slope, 'Sea Surface Temperature' and 'Distance to Desal or Power Plant' were overridden with uncertainty, as the 95% CI stretched across the entire plot, making the results rather unmeaningful, though the trends line in the 'Depth' and 'Slope' plots both display an increase in probability of occurrence with the increase of both variables. Lastly, 'Bottom Content' presents higher variability in probability of occurrence in areas where the bottom consists of sand and rock (Table 14).

Tweedie – The 2 explanatory variables retained in model 'Hot Season - Non-Correlated Data, Trawler Excluded' following model selection were 'Depth' and 'Distance to Desal and Power Plants', both of which were found to be statistically significant. The plot for 'Depth' presented a peak in probability of occurrence at a depth of approximately 130m, though due to the low number of sightings at that depth and high uncertainty, this result is unreliable. The plot for 'Distance to Desal and Power Plants' presented overall low probability of occurrence, with a decreasing trend as distance increases (Table 14).

Cold Season – Non-Correlated Data, Trawler Excluded

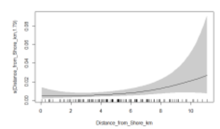
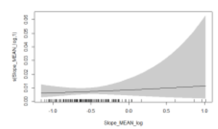
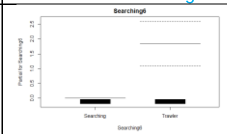
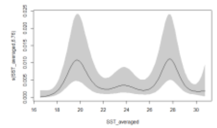
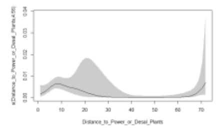
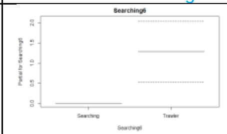
Negative Binomial - The explanatory variables retained in model 'Cold Season - Non-Correlated Data, Trawler Excluded' following model selection were 'Depth', 'Distance to Rivers or Artificial Nutrient Sources', 'Bottom Content' and 'Artificial Submerged Structures'. None of these four variables were statistically significant (Table 14).

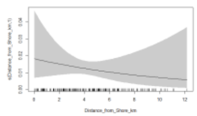
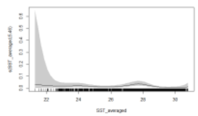
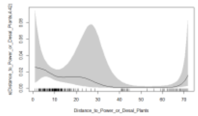
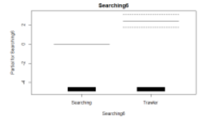
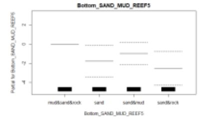
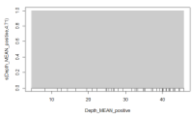
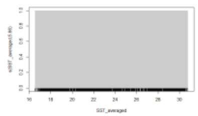
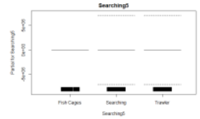
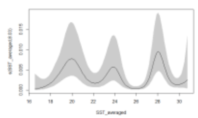
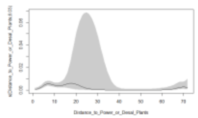
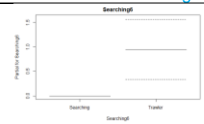
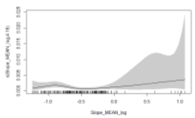
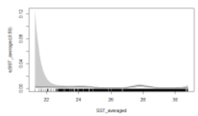
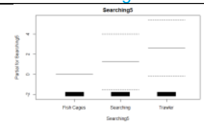
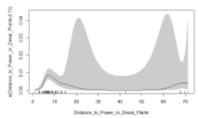
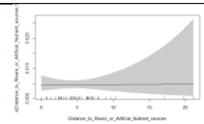
Tweedie - The two explanatory variables retained in model 'Cold Season - Non-Correlated Data, Trawler Excluded' following model selection were 'Sea Surface Temperature' and 'Distance to Desal or Power Plants', of which only the latter was found to be statistically significant but presented overall low probability of dolphin occurrence across the entire plot (Table 14).

Table 12. Summary of models from the 'non-correlated' data, and the 'search-only non-correlated' data. Information includes number of sightings within the subset, number of zero values, deviance explained for both Negative Binomial and Tweedie models, and names of explanatory variables for both Negative Binomial and Tweedie models.

Model name	Dolphin Observations	Zeros	% Deviance Explained (NB)	Variable names (NB)	% Deviance Explained (TW)	Variable names (TW)
1999-2009	94	5,717	12	SEARCHING + SHORE + SLOPE	8	SEARCHING
2010-2019	112	10,989	21	DESAL + SST + SEARCHING	21	SST + DESAL + SEARCHING
Hot Season	119	9,944	23	DESAL + SEARCHING + SHORE + SST+ BOTTOM	16	SST + SLOPE + SEARCHING
Cold Season	113	9,088	19	SEARCHING + DEPTH + SST	17	DESAL + SEARCHING + NUTRIENTS
1999-2009 - Searching	40	4,698	20	SST + BOTTOM + DESAL + DEPTH	5	SST
2010-2019 - Searching	64	92,71	34	SST + DESAL + SHORE + DEPTH	14	DESAL + DEPTH
Hot Season - Searching	53	8,214	24	BOTTOM + SST + DESAL + DEPTH + SLOPE	15	DESAL + DEPTH
Cold Season - Searching	58	7,594	14	DEPTH + BOTTOM + WRECK + NUTRIENTS	15	DESAL + SST

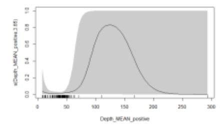
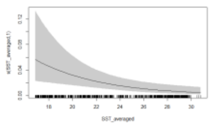
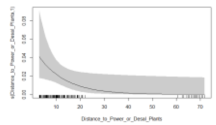
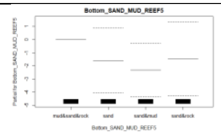
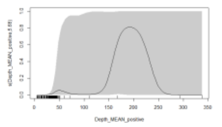
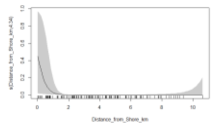
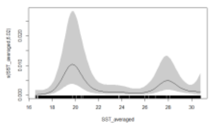
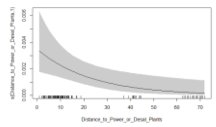
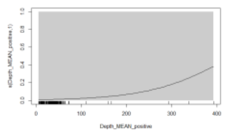
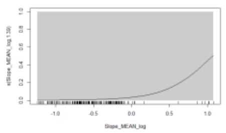
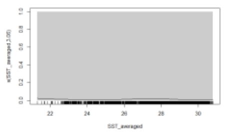
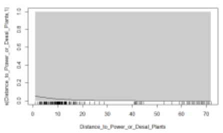
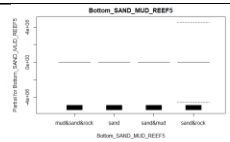
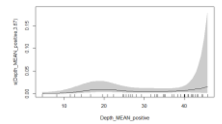
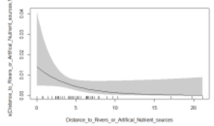
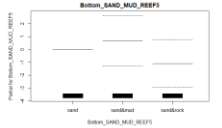
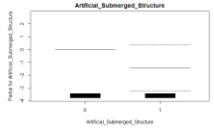
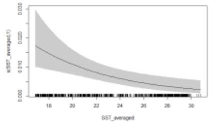
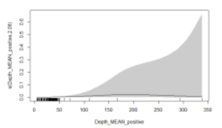
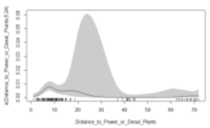
Table 13. Final models for *Tursiops truncatus* distribution, as run on the 'non-correlated' dataset for years 1999-2009, and years 2010-2019, Hot Season, and Cold Season. Results utilizing Negative Binomial distribution are displayed, followed by results utilizing Tweedie distribution. Variables that are statistically significant have names marked in blue. All vertical axes indicate the probability of dolphin occurrence on a scale of 0 to 1 (except instances where scale is minimized for clarity), while horizontal axes are presented in the units of the relevant explanatory variable, and above the horizontal axis are markings, indicating number of non-zero observations at that value of explanatory variable. Gray shaded areas represent 95% Confidence Interval.

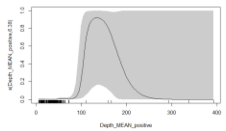
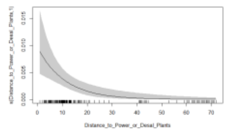
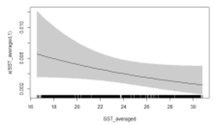
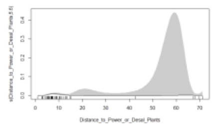
Non-Correlated Data – Negative Binomial								
1999-2009 Depth	1999-2009 Shore	1999-2009 Slope	1999-2009 SST	1999-2009 Desal	1999-2009 Nutrients	1999-2009 Searching	1999-2009 Bottom	1999-2009 Structure
								
2010-2019 Depth	2010-2019 Shore	2010-2019 Slope	2010-2019 SST	2010-2019 Desal	2010-2019 Nutrients	2010-2019 Searching	2010-2019 Bottom	2010-2019 Structure
								
Hot Depth	Hot Shore	Hot Slope	Hot SST	Hot Desal	Hot Nutrients	Hot Searching	Hot Bottom	Hot Structure

								
Cold Depth	Cold Shore	Cold Slope	Cold SST	Cold Desal	Cold Nutrients	Cold Searching	Cold Bottom	Cold Structure
								
Non-Correlated Data – Tweedie								
1999-2009 Depth	1999-2009 Shore	1999-2009 Slope	1999-2009 SST	1999-2009 Desal	1999-2009 Nutrients	1999-2009 Searching	1999-2009 Bottom	1999-2009 Structure
								
2010-2019 Depth	2010-2019 Shore	2010-2019 Slope	2010-2019 SST	2010-2019 Desal	2010-2019 Nutrients	2010-2019 Searching	2010-2019 Bottom	2010-2019 Structure
								
Hot Depth	Hot Shore	Hot Slope	Hot SST	Hot Desal	Hot Nutrients	Hot Searching	Hot Bottom	Hot Structure
								
Cold Depth	Cold Shore	Cold Slope	Cold SST	Cold Desal	Cold Nutrients	Cold Searching	Cold Bottom	Cold Structure
								

* Depth = Depth (m), Shore = Distance to Shore (km), Slope = log(Slope), SST = Sea Surface Temperature (°C), Desal = Distance to Desalination or Power Plants (km), Nutrients = Distance to Rivers or Artificial Nutrient Sources (km), Searching = Searching (randomized)/Trawler (in vicinity)/Fish Cages (in vicinity), Bottom = Type of substrate (mud/sand/rock), Structure = Artificial Submerged Structure (present/not present).

Table 14. Final models for *Tursiops truncatus* distribution, as run on the 'non-correlated searching-only' dataset for years 1999-2009, and years 2010-2019, Hot Season, and Cold Season. Results utilizing Negative Binomial distribution are displayed, followed by results utilizing Tweedie distribution. Variables that are statistically significant have names marked in blue. All vertical axes indicate the probability of dolphin occurrence on a scale of 0 to 1 (except instances where scale is minimized for clarity), while horizontal axes are presented in the units of the relevant explanatory variable, and above the horizontal axis are markings, indicating number of non-zero observations at that value of explanatory variable. Gray shaded areas represent 95% Confidence Interval.

Non-Correlated Trawler Excluded Data – Negative Binomial							
1999-2009 Depth	1999-2009 Shore	1999-2009 Slope	1999-2009 SST	1999-2009 Desal	1999-2009 Nutrients	1999-2009 Bottom	1999-2009 Structure
							
2010-2019 Depth	2010-2019 Shore	2010-2019 Slope	2010-2019 SST	2010-2019 Desal	2010-2019 Nutrients	2010-2019 Bottom	2010-2019 Structure
							
Hot Depth	Hot Shore	Hot Slope	Hot SST	Hot Desal	Hot Nutrients	Hot Bottom	Hot Structure
							
Cold Depth	Cold Shore	Cold Slope	Cold SST	Cold Desal	Cold Nutrients	Cold Bottom	Cold Structure
							
Non-Correlated Trawler Excluded Data – Tweedie							
1999-2009 Depth	1999-2009 Shore	1999-2009 Slope	1999-2009 SST	1999-2009 Desal	1999-2009 Nutrients	1999-2009 Bottom	1999-2009 Structure
							
2010-2019 Depth	2010-2019 Shore	2010-2019 Slope	2010-2019 SST	2010-2019 Desal	2010-2019 Nutrients	2010-2019 Bottom	2010-2019 Structure
							
Hot Depth	Hot Shore	Hot Slope	Hot SST	Hot Desal	Hot Nutrients	Hot Bottom	Hot Structure

							
Cold Depth	Cold Shore	Cold Slope	Cold SST	Cold Desal	Cold Nutrients	Cold Bottom	Cold Structure
							

* Depth = Depth (m), Shore = Distance to Shore (km), Slope = log(Slope), SST = Sea Surface Temperature (°C), Desal = Distance to Desalination or Power Plants (km), Nutrients = Distance to Rivers or Artificial Nutrient Sources (km), Bottom = Type of substrate (mud/sand/rock), Structure = Artificial Submerged Structure (present/not present).

Prediction Maps – Non-Correlated Data, Trawler excluded

Negative Binomial - Based on the 'Non-Correlated Data, Trawler excluded' models, 4 prediction maps were created, displaying the probability of occurrence for *T. truncatus* along the Israeli continental shelf (Figure 16). The maps visualize that while certain explanatory variables had stronger effects on the final prediction, all plots display higher probability of occurrence in a corridor, parallel to the shore, at a mid-way distance to the edge of the continental shelf.

Tweedie – As the 'Non-Correlated Data, Trawler excluded' models based on Tweedie distribution presented only one significant variable or less, no meaningful maps could be produced.

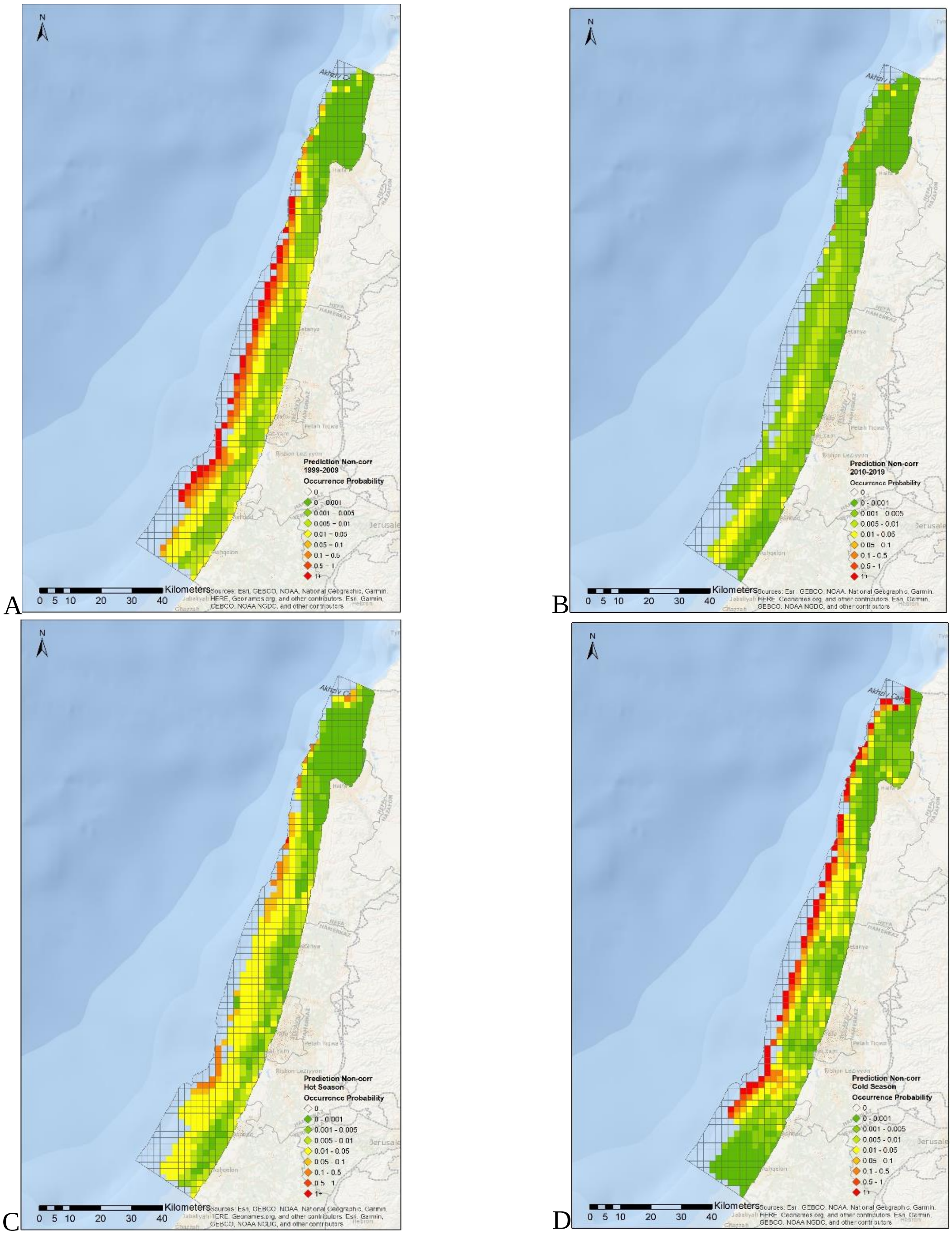


Figure 16. Prediction Map for *Tursiops truncatus* based on 'non-correlated, trawler excluded' data. A) Prediction from the years 1999-2009, B) Prediction from the years 2010-2019, C) Prediction from the 'Hot Season', D) Prediction from the 'Cold Season'.

3.4 MODELS - DELPHINUS DELPHIS

3.4.1 Temporal Subsets

The three models based on the subsets created for *D. delphis*, and Negative Binomial distribution presented deviance explained values that varied between 29% and 41%, while number of explanatory variables varied between 2 - 5 (Table 15, Table 16). ‘Depth’, ‘Distance to Shore’ and ‘Searching’ were the three variables that were retained in more than one model.

The three models based on the subsets created for *D. delphis*, and Tweedie distribution presented deviance explained values that varied between 16% and 19%, and all three models only retained ‘Depth’ as the singular explanatory variable (Table 15, Table 16).

3.4.2 Non Correlated Data

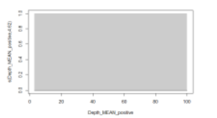
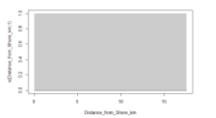
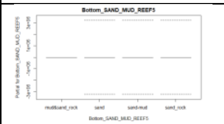
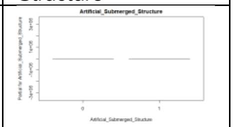
The ‘Non-Correlated Data’ models based on Negative Binomial distribution presented deviance explained values that varied between 6% and 26%, while number of explanatory variables was either 1 or 2 – ‘Depth’ and ‘Searching’ (Table 15, Table 16).

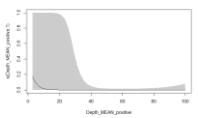
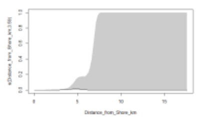
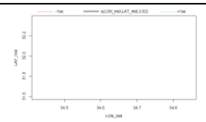
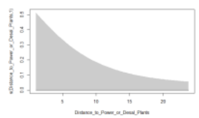
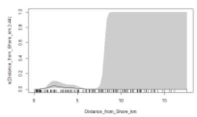
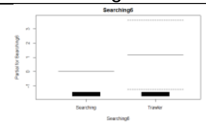
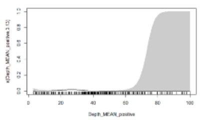
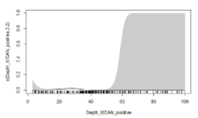
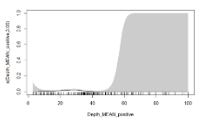
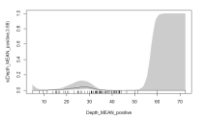
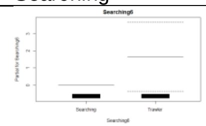
The ‘Non-Correlated Data’ models based on Tweedie distribution presented deviance explained values that varied between 6% and 26%, while each model retained only one explanatory variables– ‘Lat, Lon’ or ‘Distance to Artificial Nutrient Sources’ (Table 15, Table 16).

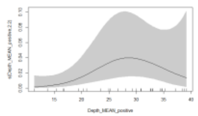
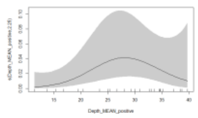
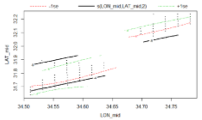
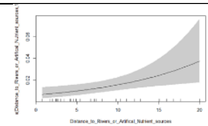
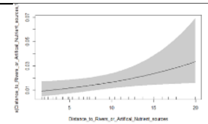
Table 15. Summary of models from the 'non-correlated' data, and the 'search-only non-correlated' data. Information includes number of sightings within the subset, number of zero values, deviance explained for both Negative Binomial and Tweedie models, and names of explanatory variables for both Negative Binomial and Tweedie models.

Model name	N dolphin Observations	N Zeros	% Non-zero	% Deviance Explained (NB)	Variable names (NB)	% Deviance Explained (TW)	Variable names (TW)
Subset 2009 Full Dataset	40	1012	3.95	38	BOTTOM + SHORE + DEPTH + WRECK + SEARCHING	16	DEPTH
Subset 2016 Full Dataset	36	1012	3.56	41	DEPTH + Lat, Lon + SHORE + DESAL	19	DEPTH
Subset 2016, Area 5 Full Dataset	35	1032	3.39	29	SHORE + SEARCHING	19	DEPTH
Subset 2009 Non-Correlated Data	36	8548	0.42	26	DEPTH + SEARCHING	7	Lat, Lon
Subset 2016 Non-Correlated Data	34	4582	0.74	7	DEPTH	3	NUTRIENTS
Subset 2016, Area 5 Non-Correlated Data	34	4332	0.78	6	DEPTH	2	NUTRIENTS

Table 16. Final models for *Delphinus delphis* distribution, as run on the complete temporal subsets and the 'Non-Correlated' temporal subsets. Results utilizing Negative Binomial distribution are displayed, followed by results utilizing Tweedie distribution. Variables that are statistically significant have names marked in blue. All vertical axes indicate the probability of dolphin occurrence on a scale of 0 to 1 (except instances where scale is minimized for clarity), while horizontal axes are presented in the units of the relevant explanatory variable, and above the horizontal axis are markings, indicating number of non-zero observations at that value of explanatory variable. Gray shaded areas represent 95% Confidence Interval.

Temporal Subsets - Negative Binomial								
Subset 2009 - Depth	Subset 2009 - Shore	Subset 2009 - Lat, Lon	Subset 2009 - SST	Subset 2009 - Desal	Subset 2009 - Nutrients	Subset 2009 - Searching	Subset 2009 - Bottom	Subset 2009 - Structure
								

Subset 2016 - Depth	Subset 2016 - Shore	Subset 2016 - Lat, Lon	Subset 2016 - SST	Subset 2016 - Desal	Subset 2016 - Nutrients	Subset 2016 - Searching	Subset 2016 - Bottom	Subset 2016 - Structure
								
Subset 2016, Area 5 - Depth	Subset 2016, Area 5 - Shore	Subset 2016, Area 5 - Lat, Lon	Subset 2016, Area 5 - SST	Subset 2016, Area 5 - Desal	Subset 2016, Area 5 - Nutrients	Subset 2016, Area 5 - Searching	Subset 2016, Area 5 - Bottom	Subset 2016, Area 5 - Structure
								
Temporal Subsets - Tweedie								
Subset 2009 - Depth	Subset 2009 - Shore	Subset 2009 - Lat, Lon	Subset 2009 - SST	Subset 2009 - Desal	Subset 2009 - Nutrients	Subset 2009 - Searching	Subset 2009 - Bottom	Subset 2009 - Structure
								
Subset 2016 - Depth	Subset 2016 - Shore	Subset 2016 - Lat, Lon	Subset 2016 - SST	Subset 2016 - Desal	Subset 2016 - Nutrients	Subset 2016 - Searching	Subset 2016 - Bottom	Subset 2016 - Structure
								
Subset 2016, Area 5 - Depth	Subset 2016, Area 5 - Shore	Subset 2016, Area 5 - Lat, Lon	Subset 2016, Area 5 - SST	Subset 2016, Area 5 - Desal	Subset 2016, Area 5 - Nutrients	Subset 2016, Area 5 - Searching	Subset 2016, Area 5 - Bottom	Subset 2016, Area 5 - Structure
								
Non-Correlated Subsets - Negative Binomial								
Subset 2009 - Depth	Subset 2009 - Shore	Subset 2009 - Lat, Lon	Subset 2009 - SST	Subset 2009 - Desal	Subset 2009 - Nutrients	Subset 2009 - Searching	Subset 2009 - Bottom	Subset 2009 - Structure
								
Subset 2016 - Depth	Subset 2016 - Shore	Subset 2016 - Lat, Lon	Subset 2016 - SST	Subset 2016 - Desal	Subset 2016 - Nutrients	Subset 2016 - Searching	Subset 2016 - Bottom	Subset 2016 - Structure

								
Subset 2016, Area 5 - Depth	Subset 2016, Area 5 - Shore	Subset 2016, Area 5 - Lat, Lon	Subset 2016, Area 5 - SST	Subset 2016, Area 5 - Desal	Subset 2016, Area 5 - Nutrients	Subset 2016, Area 5 - Searching	Subset 2016, Area 5 - Bottom	Subset 2016, Area 5 - Structure
								
Non-Correlated Subsets - Tweedie								
Subset 2009 - Depth	Subset 2009 - Shore	Subset 2009 - Lat, Lon	Subset 2009 - SST	Subset 2009 - Desal	Subset 2009 - Nutrients	Subset 2009 - Searching	Subset 2009 - Bottom	Subset 2009 - Structure
								
Subset 2016 - Depth	Subset 2016 - Shore	Subset 2016 - Lat, Lon	Subset 2016 - SST	Subset 2016 - Desal	Subset 2016 - Nutrients	Subset 2016 - Searching	Subset 2016 - Bottom	Subset 2016 - Structure
								
Subset 2016, Area 5 - Depth	Subset 2016, Area 5 - Shore	Subset 2016, Area 5 - Lat, Lon	Subset 2016, Area 5 - SST	Subset 2016, Area 5 - Desal	Subset 2016, Area 5 - Nutrients	Subset 2016, Area 5 - Searching	Subset 2016, Area 5 - Bottom	Subset 2016, Area 5 - Structure
								

* Depth = Depth (m), Shore = Distance to Shore (km), Slope = log(Slope), SST = Sea Surface Temperature (°C), Desal = Distance to Desalination or Power Plants (km), Nutrients = Distance to Rivers or Artificial Nutrient Sources (km), Searching = Searching (randomized)/Trawler (in vicinity)/Fish Cages (in vicinity), Bottom = Type of substrate (mud/sand/rock), Structure = Artificial Submerged Structure (present/not present).

4.1 POPULATION SIZE ESTIMATION

The main methodology used for estimation of population size in this work is based on principles of distance sampling (Buckland et al., 2015), which have several key assumptions. One of the main assumptions is that animals are distributed independently of the survey lines and that the survey effort evenly covers the study area in a randomized pattern. These assumptions were not met throughout the field work and has likely skewed the results of dolphin abundance estimations in Israel. Due to the majority of the survey effort being concentrated near marinas, and near shore, results may present an overestimation of abundance in the event that dolphins present higher occurrence in these areas, or alternatively an underestimation if dolphins present higher occurrence in other areas. As model results are not conclusive regarding areas of higher dolphin occurrence- this is hard to determine with certainty.

Additionally, surveys are not conducted in an entirely randomized pattern, as the survey vessel often approaches trawlers intentionally or travels to areas when *D. delphis* is most often observed. Regarding survey effort for *T. truncatus*- survey methodology has been consistent and search patterns have been mostly randomized (with the exception of trawler approachment) throughout the entire study period, though survey coverage has not been even across the study area. However, survey effort for *D. delphis* has not followed the methodology quite as rigorously. In recent years, survey effort in the south of Israel has increased, in order to closely observe and study the *D. delphis* population. Repeated field observations have enabled researchers to anticipate the whereabouts of these dolphin groups, resulting in search effort that is biased towards areas that this population frequents.

Due to this difference in survey method, the population size estimations for *T. truncatus* are likely a closer reflection of the true abundance (135 ± 15, individuals ± 95% CI), while the most recent population size estimation for *D. delphis* (79 ± 11, individuals ± 95% CI) likely represents an overestimation of the population, and the 2018 estimation (42 ± 13, individuals ± 95% CI), before surveying according to anticipation of group locations, was likely more accurate, for that period of time.

These results for population size estimations were slightly higher than abundance estimations conducted over the same time period by Yaly Mevorach during her M.Sc. study on the same coastal dolphin populations, using mark-recapture protocols based on photo ID. Yaly estimated *T. truncatus'* total abundance on a seasonal basis, and mean estimations ranged from 45 to 130 during different years and seasons. Additionally, *D. delphis'* total abundance was estimated to be 23 adult individuals during 2016 and has recently been updated to 12, possibly due to emigration or death of several individuals.

An alternative method of population size estimation by use of model predictions was attempted for the *T. truncatus* population, and although all results presented abundance estimates within a similar range, these estimations (between 17-31 individuals) are unsound and present an under-prediction. This determination can be made rather conclusively as the photo-ID catalog in Israel contains 185 significantly marked individuals, 98 or which were sighted on multiple occasions (Mevorach 2021). It is apparent that while the Israeli dolphin survey dataset may be appropriate for modelling habitat preferences, it is not suitable for model-based abundance estimates, as all model-based estimates were considerably lower than estimations made based on concepts from Distance Sampling, and also compared to the photo-ID catalog. The under-estimation of *T. truncatus* abundance is likely a result of the zero-inflated structure of the data set (as explained in Chapter 2.4.2), which resulted in artificial over-expression of 'absence of sightings' due to the high segmentation of the dataset.

4.2 OCCURANCE MAPS

Spatial Occurrence Maps

The spatial occurrence maps present a preference of both species towards the south of Israel. *T. truncatus* presented higher probability of occurrence near the deep end of the continental shelf, both in the mid-section and the southern section of the study area, while *D. delphis* presented higher probability of occurrence in the shallow near-shore region of the south section only. The *T. truncatus* plots emphasized the difference between data interpretation with models based on Negative Binomial distribution vs models based on Tweedie distribution, as a marked difference could be observed between the predictions of these two distributions. It appears that the Negative Binomial distribution predicts a more gradual pattern of distribution, with a smoother transition between higher and lower predictions of dolphin occurrence. The pattern evident in the Negative Binomial distribution is likely a result of this distribution's ability to deal with higher variability within the data, hence the final prediction result is not jarred by extreme values across different sections of the study area.

Non-Correlated Data Occurrence Maps

The occurrence maps for *T. truncatus* resulting from the non-correlated data, display a randomized pattern in sightings-per-unit effort in all areas where search effort surpassed the minimum threshold. With the exception of the Haifa Bay area, where only one sighting occurred, all areas of the continental shelf that were surveyed resulted in significant presence of dolphins, across both 10-year time periods. This leads us to the understanding that *T. truncatus* are uniformly distributed across most sections of the continental shelf, though Haifa Bay may present lower density.

Additionally, it is reasonable to make a careful interpretation regarding the survey effort threshold, which increased between the two 10-year periods, and the number-of-sightings-per-unit-survey-effort values, which decreased between the two 10-year periods, and conclude that a possible decline in *T. truncatus* density has occurred between these time periods.

The occurrence maps for *D. delphis* resulting from the non-correlated data, display a clustered pattern in sightings-per-unit-effort in the very south of the study area, between Ashdod and Ashkelon, with values increasing towards the south. Two clusters of areas with sufficient search effort to surpass the minimum threshold are displayed, and the northern cluster presents scarce sightings and low sightings-per-effort values. It is unknown whether a gradient would be evident between these two clusters, if search effort was sufficient, or if *D. delphis* are present even further south, as the extent of the study area is limited by international borders.

The main conclusion gained from these maps is the certain regular occurrence of *D. delphis* near Ashdod and Ashkelon, and their lower presence near Hertzliya (the northern cluster).

4.3 MODELS - OVERVIEW

The most predominant explanatory variable across all *T. truncatus* models was the 'Searching' variable, which indicated that *T. truncatus'* probability of occurrence was higher in the vicinity of trawlers than in open water. Additionally, 'Distance to Desalination or Power Plants' was significant throughout many of the models, with the likeliest explanation for this result attributed to the proximity of these facilities to the marinas which provided the start and end points for the majority of surveys. Lastly, 'Sea Surface Temperature' was significant across multiple models, though trends displayed in the plots were highly variable and, in many cases, may have presented overfitting of the data. Due to the high dependency of *T. truncatus* on trawlers across most models- mapping the results would be insensible as the locations of trawlers are inconsistent both spatially and temporally.

Trawler Excluded Models for *T. truncatus* presented various significant parameters across the different models, though when mapped, the majority of models displayed a corridor of higher probability of dolphin occurrence, running parallel to the coast. The main environmental factor driving this trend cannot be determined conclusively as elevated probability of occurrence in this zone may be attributed to depth, distance from shore, or anticipation of trawlers along their most routine fishing paths.

The most predominant explanatory variable across all *D. delphis* models was the 'Depth' variable, and although this provides rather conclusive results, the latitudinally limited distribution of this population was unexplainable by use of modeling, as was the difference in depth preference compared to other populations of *D. delphis* in the Mediterranean which frequent deeper waters.

Overall, the *T. truncatus* models strengthened the conclusions of Scheinin (2010), which found *T. truncatus* in Israel to frequently associate with trawlers. However, the models for both species were not able to support or disprove the hypothesis of this study, which assumed the distribution of dolphins to be influenced by prey distributions. Actual data on prey distribution was unavailable across the entire study area and many of the proxies for prey distribution such as 'chlorophyll *a*' and bottom composition, were too patchy to for the models to utilize effectively.

4.4 MODELS - *TURSIOPS TRUNCATUS*

4.4.1 Spatial and Temporal Models

Full Data Set

Four parameters were significant across all three temporal subsets, for both Negative Binomial and Tweedie models- ‘Distance to Desal or Power Plants’, ‘Distance to Shore’, ‘Sea Surface Temperature’ and ‘Searching’. Of these, only ‘Searching’ and ‘Distance to Shore’ provided reasonable explanations, to our best understanding, for dolphin distribution from an ecological perspective.

The ‘Searching’ parameter, across all three models, showed that probability of dolphin occurrence was higher in the vicinity of trawlers, thereby strengthening the observation that dolphins utilize trawlers and their nets as mobile feeding points (Scheinin et al., 2014). Many previous studies have demonstrated dolphins’ relationship and dependency on trawlers, both in Israel, in other parts of the Mediterranean, and worldwide (Lousie et al., 2001; Genov et al., 2008; Rayment et al., 2009; Scheinin 2010; Pleslić et al., 2015; Genov et al., 2019; Bonizzoni et al., 2021).

The ‘Distance to Shore’ plot shows a high density of dolphin sightings between 0-12 km from shore (markings on bottom of plot), and presents an overall low probability of occurrence, across all three temporal subsets. Additionally, a slight increase in probability of occurrence can be observed at approximately 8 km from shore, at most plots.

The ‘Distance to Desal or Power Plants’ parameter is difficult to explain from an ecological perspective as any trends observed at distances greater than several kilometers are likely an artifact, since the effects of desal and power plants (warm / highly saline water) do not carry on to such great distances due to dilution. The effects displayed in these models and various other datasets are likely related to the close vicinity between desal plants, power plants and major marinas, from which the survey vessels depart, hence creating elevated survey effort in their vicinity.

The ‘Sea Surface Temperature’ parameter displays different trends across the two decades (1999-2009 / 2010-2019). While it may be possible that dolphin distribution differed in relation to temperature over time, it is also possible that the data did not fit this parameter well during one of the two time periods. The apparent conclusions from these plots are that dolphin occurrence either decreases with a rise in temperature, or that dolphins show preferences towards occasions where the temperature is 20° or 28° C (early winter or early summer).

Other parameters displayed plots with trends that varied greatly between models or displayed exceptionally high uncertainty and are therefore difficult to draw conclusions from.

Although ‘Distance to Rivers or Artificial Nutrient Sources’ was only included in the ‘2010-2019’ Negative Binomial model and ‘All Years’ Tweedie model, it should also be noted that the effects of excess nutrients from artificial sources are typically prevalent up to a few kilometers from the source (or less), and so, similarly to ‘Distance to Desal or Power Plants’ this parameter is also somewhat difficult to explain from an ecological perspective at great distances.

Hot / Cold Seasons

Across the 'Hot Season' models, the only parameter that was significant in all models was the 'Searching' parameter, which emphasizes the observation that dolphins associate strongly with trawlers, in order to feed. All other parameters were significant in either the '1999-2009' model or the '2010-2019' model, and in some cases influenced the 'All Years' model causing the results to display a near-identical trend for that parameter. Comparison between the Negative Binomial models and the Tweedie models shows similar results, though the Tweedie models found significance in fewer parameters.

Across the 'Cold Season' models, no parameters were significant for all three models or for both the '1999-2009' model and the '2010-2019' model. Overall, dolphin distribution and habitat preferences appear unpredictable during the 'Cold Season' and is not as strongly associated with trawlers as was observed in the 'Hot Season'. Comparison between the Negative Binomial models and the Tweedie models shows differing results across 'Cold Season' models, both in terms of significant parameters, and trends observed for the parameters retained. This further emphasizes the unpredictability of the results for the 'Cold Season'

Several possible reasons can be attributed to the difference between association with trawlers when comparing the 'Hot Season' and 'Cold Season'; 1) Differences in trawler patterns, 2) Differences in prey availability in the natural environment and therefore differences in foraging strategies, 3) Differences in energetic budgets between seasons, resulting in differences attributed to foraging strategies.

Trawl haul has been shown by Stern (2010) to change across the seasons, with recorded differences in total abundance, biomass and species composition. In all categories, significant differences were found between summer hauls, presenting higher values in comparison to other seasons, which varied across the different categories examined. This observation demonstrates that it is therefore possible that foraging trawler nets during the 'Hot Season' is more rewarding to *Tursiops truncaus* in comparison to other times of the year.

The 'Hot Season' is also typically the calving season for *T. truncatus* in Israel (Scheinin 2010), an energetically costly stage for the females who may be utilizing the trawlers' catch to enhance or supplement their diet.

Trawl patterns have not been continuously recorded across the entire study period and have changed over the years, due to multiple reasons. In the past, trawling was permitted across most of the continental shelf (study area) and according to Pisanty's 2006 report- preferred areas included the shallow section between Jaffa and Ashkelon (23.4% of annual working hours), the deep section between Jaffa and Ashkelon (16.7% of annual working hours), the deep section between Carmel and Jaffa (13% of annual working hours) and Haifa Bay (13.5% of annual working hours). These numbers indicate that both the shallow and deep waters of the southern section of the continental shelf (equivalent to environmental Areas 4 and 5) are areas with elevated presence of working trawlers, in comparison to the remainder of the continental shelf. An additional boost to the trawl fishery in the south was the start of a shrimp fishery in the 1980's, following the Lessepsian invasion of three different species of prawn. This shrimp fishery has been recorded to brings in a quarter of the total trawl catch volume (Galil, 2007).

During 2016, fishing legislation in Israel was changed and trawling was prohibited in any area's north of 'Habonim' (תקנות הדיג, 1937, סעיף 8) which is equivalent to the environmental Areas 1, 2, and part of 3, as defined in this study (Chapter 2.4.4). Additionally, a 2-month trawling ban across the entire continental shelf waters was also put in place during the summer, the spawning season for groupers and other large rocky-bottom fish.

Areas 1 / 2 / 3 / 4 / 5

Area 1. The lack of significant results, and large uncertainty across most plots in 'Area 1' are indicative of insufficient survey coverage in this area to draw conclusions on dolphin distribution and habitat preferences through modeling. This is true for both Negative Binomial models, and Tweedie models.

Area 2. 'Area 2' was not possible to model at all since only 1 *T. truncatus* sighting occurred in this area across the whole study period.

Area 3. 'Area 3' presented inconsistency in significant parameters between models. This statement holds true when comparing between Negative Binomial and Tweedie distribution, but also when comparing between time periods. Nevertheless, the 'All Years' models utilizing Negative Binomial and Tweedie, both presented 'Searching' and 'Distance to Desal or Power Plants' as significant parameters, and the '1999-2009' models also showed 'Searching' to be significant. As previously mentioned, the presence of trawlers appears to affect the presence of dolphins, an observation that also holds true in this area. Overall, it appears that 'Area 3' produced weak models for each individual decade, and the distribution chosen for the model had a large effect on the results.

Area 4. In 'Area 4', the parameter 'Searching' were significant across all three models for both Negative Binomial and Tweedie distribution. 'Sea Surface Temperature' was also significant in all three Negative Binomial models. These results are similar to those of the temporal models created from the full dataset, and indicate the data collected in 'Area 4' has a strong influence on the entire dataset. The 'Searching' parameter clearly emphasizes the dolphins' affinity to trawlers, while the 'Sea Surface Temperature' parameter presents results that are not as straight-forward, as trends differ greatly between the '1999-2009' and '2010-2019' Negative Binomial models. The only conclusive result from this section remains the affinity of dolphins to trawlers.

Area 5. 'Area 5' presented very few significant parameters, which is to be expected considering the minimal search effort that was executed during the years 1999-2009. The only significant parameter observed across multiple models is 'Searching' which presents higher probability of dolphin occurrence in the vicinity of the fish cages. The offshore fish cages in 'Area 5' are large and productive and provide a strong attracting point for dolphins (MKMRS acoustic recorders - unpublished data) that forage at the top of localized food webs, based on deposits from this facility.

4.4.2 Trawler Excluded Models

The ‘Trawler Excluded’ models presented different significant parameters, in each of the four models. Across the Negative Binomial models ‘Depth’ and ‘Distance to Desal or Power Plants’ were significant in multiple models, though they showed different and even opposite trends across the plots. The Tweedie based models also showed high variability between them, and few significant parameters. Nevertheless, three of the four parameters retained in the model for ‘Areas 3, 4 & 5 combined’, were the same between the two distributions utilized.

Geographically, Areas 3, 4 and 5 are very similar to each other in terms of the shape of the coastline, the prevailing currents, the slope and aspect of the bottom. Due to the geographical similarity, it would be expected that the dolphins’ distribution and habitat preferences in these sections would be similar, but the lack of similarity between models suggests that the dataset is insufficient to describe the environmental parameters influencing dolphin distribution in these areas.

The prediction maps created from these models also varied greatly between them, indicating that the models were not able to identify and predict a reliable set of environmental parameters or a distribution pattern for dolphins in Areas 3, 4 and 5. However, the prediction maps based on the Negative Binomial and Tweedie distributions for ‘Areas 3, 4 & 5 combined’, did present similarity between them and predicted a certain offshore “corridor” running parallel to shore, with higher probability of dolphin occurrence. It should be noted that this “corridor” may also be influenced by the presence of trawlers and aligns with the known trawl patterns in the region. It is possible that dolphins are frequenting this area in an attempt to locate active trawlers.

4.4.3 Non - Correlated Data

Narrowing down the dataset to only the sections where no correlation is found between sightings and search effort causes removal of much of the data. The remaining data, utilized in this set of models, was not sufficient for construction of spatial models across different geographical sections of the study area.

Comparison of all four models clearly emphasizes the affinity of the dolphins to trawlers, due to the significance of the ‘Searching’ parameter across all models. Differences between decades or seasons were not as obvious, as the significant parameters varied between both sets of models. Additionally, the parameters that were similar between models either displayed mild trends with high uncertainty, such as the ‘Distance to Desal or Power Plants’ parameter, or highly variable trends that are likely overfitted, such as ‘Sea Surface Temperature’.

4.4.4 Non - Correlated Data, Trawler Excluded Models

This set of models likely best describes *T. truncatus* habitat preferences along the continental shelf of Israel due to the filtration process of the data. Although the Negative Binomial model results are difficult to interpret from the individual parameter plots, several observations can be made. The ‘Distance to Desal or Power Plants’ parameter is significant across three models, with similar trends between the ‘1999-2009’ and ‘2010-2019’ models, and a different trend during the ‘Hot Season’ model.

From an ecological perspective, it is difficult to explain why this parameter is so central to this set of models, and also to many of the other models presented in this research, but it is possible that the locations of these facilities correlate with industrialized areas of the coast that may have additional effects on dolphin distribution, or alternatively, these areas may receive frequent survey coverage due to their proximity to major marinas.

The 'Sea Surface Temperature' parameter was also retained in the same three models, and although trends varied between plots, the significance of this parameter indicates that changes in temperature effect dolphin distribution. 'Depth' was retained in all four models, though in most cases this parameter was not statistically significant.

'Distance from Shore' was only retained in one model, while 'Bottom Content' was retained in the three models that did not include 'Distance from Shore'. Although the trends in these parameters are difficult to interpret, their inclusion in the models is an indication that the depth, distance from shore and the physical parameters of the seafloor all influence dolphin distribution.

The prediction maps created from the Negative Binomial models display a general similarity, as they all predict a certain corridor, running parallel to shore, where probability of dolphin occurrence is higher than other parts of the study area. Additionally, predictions near Haifa and northwards were low, with the exception of several very specific points. Although this may be due to lack of data collected in these areas, the section of the Israeli coast from the Haifa Bay and northwards has different environmental characteristics, particularly in terms of currents and seafloor composition. This difference in conditions may cause a difference in distribution patterns but may also cause prediction challenges for the models.

On the contrary, the Tweedie models for this dataset are uninformative and present weak predictions, with only one or two significant parameters in each model. These results are insufficient for the creation of prediction maps and therefore none are presented.

4.5 MODELS - *DELPHINUS DELPHIS*

The modeling results for *D. delphis* were quite surprising and insightful. Although they utilized a small number of sightings for the modeling process (40 or less), they provided informative results and also emphasized the difference in result from models based on different distributions.

Across the temporal subsets all Tweedie based models retained 'Depth' as the only explanatory parameter and presented similar plots with a small peak in probability of abundance around 30m depth followed by high uncertainty from 50m depth and onwards. The Negative Binomial models based on the same subsets retained a variety of different parameters, that were inconsistent between models and difficult to interpret from an ecological perspective.

Across the 'non-correlated' temporal subsets it was the Negative Binomial models that retained 'Depth' as an explanatory parameter for all three models ('subset 2009' also included 'Searching'). The 'non-correlated' subsets based on Tweedie distribution retained either 'Lat, Lon' or 'Distance from

Artificial Nutrient Sources' as their singular explanatory parameters, and these are either uninformative on such a small scale, or difficult to interpret from an ecological perspective.

It is interesting, and somewhat counter-intuitive that the Negative Binomial distribution found 'Depth' to be significant across all temporal subsets, while the Tweedie distribution resulted in the same observation ('Depth' being significant) for the temporal 'non-correlated' subsets. The process of reducing the dataset to 'non-correlated' survey effort and sightings should minimize the variability within the dataset, thereby giving an advantage to the Tweedie distribution that is advantageous for zero-inflated data, but not necessarily for over-dispersed data. Results show the opposite of expected and highlight the complexity of these distributions and the challenges of fitting the most appropriate distribution to a dataset with an atypical structure.

5 Conclusion

5.1 *TURSIOPS TRUNCATUS*

Models that included a large number of dolphin sightings (such as the 'full database', '1999-2009' or '2010-2019'), introduced high variability within the explanatory parameters. Although both the Negative Binomial and Tweedie based models provided similar results for these datasets- the plots often displayed results that were difficult to explain from an ecological perspective, and in some cases, likely overfitted the data.

On the other hand, models based on specified datasets that described particular spatial areas or time periods, included smaller numbers of dolphin sighting and less variability within the explanatory parameters. These models presented less similarity between Negative Binomial and Tweedie based model results. The Negative Binomial models found significance in a larger number of parameters in comparison to the Tweedie models, and it is hard to determine which is a better representation of the ground truth.

Across most models, the 'Searching' parameter was significant and emphasized the affinity of *T. truncatus* to trawlers, which act as a mobile food source. Additionally, in areas where fish cages are present, the models also show that probability of occurrence is higher in their vicinity. These findings match the findings of Scheinin (2014) and ongoing work at MKMRS that has found elevated presence of dolphins in the vicinity of fish cages in Israel based on data from long-term passive acoustic recording devices (C-Pod), which detect dolphin presence according to echolocation (unpublished data). Upon comparison of seasons during which the seawater was 'hot' or 'cold', model results showed that vicinity to trawlers was significant during the 'hot season', but not significant during the 'cold season'. These differences are possibly related to differences in trawl hauls between seasons and the energetic advantage of utilizing trawler nets for foraging, particularly in light of the Eastern Mediterranean's highly oligotrophic nature (McCall 2008) and the variation of prey distribution and availability across seasons (Stern, 2010; Roditi et al., 2019).

All prediction maps created from 'trawler excluded' data displayed a corridor running parallel to shore, with higher probability of dolphin occurrence. These corridors varied between models, with some presenting a narrower/wider region, some presenting higher/lower probability of occurrence and some closer/farther from shore, or slight variations in depth. Overall, the corridors were mostly between 5-10 km offshore, and 40-70m depth. This is true for both Negative Binomial and Tweedie models based on Areas 3, 4 & 5, and all Negative Binomial models from the non-correlated dataset. Whether driven by distance from shore, depth, or typical trawling patters, *T. truncatus* appear to prefer a certain "strip" of the continental shelf.

Overall, it appears that the study area does not present sufficient natural variability to provide preferred areas of occurrence for *T. truncatus*, and they are therefore dispersed at random across the Israeli continental shelf, possibly with the exception of a certain "corridor" parallel to shore.

Future Research:

Following up on the finding of this study, future research should include ‘presence only’ models, based on sightings reported by the general public. With the rapid advancement of technology and accessibility of smartphones in the last decade, it is easier than ever to report a dolphin sighting at sea, and the citizen science database includes 200-300 sightings per year.

An additional recommendation for following up on this study would be increase data collection in the north of Israel, particularly in the area northwards of ‘Dor’ settlement, as this area has been closed to trawlers since 2016 and can provide a reference for dolphin distribution in true absence of trawlers.

Model results showing lack of association with trawlers during the ‘cold season’ should be followed by further examining data from the ‘cold season’ and utilizing additional information collected during the vessel-based surveys such as behavior and overall swimming track. Also, if possible, it would be advantageous to conduct increased survey effort during upcoming ‘cold seasons’.

Lastly, the main challenge and “Achilles’ heel” of this research was the uneven distribution of survey effort across the study area. The spatial clustering in survey effort created a need to fragment the dataset in such a way that it became excessively zero inflated. Future modeling work would benefit from a systematic survey design, based on linear transects. Transects should be conducted perpendicular to the shore and extend until the continental slope (min 200m depth). Considering the length of the Israeli coast (196 km), transects should be conducted every 10-15 km to allow for adequate representation of the entire study area. Vessel speed should be approximately 10 knots, as according to Hiby, 1982, vessel speed should be 2-3 faster than speed of cetacean to avoid positive bias, and *T. truncatus'* typical swim speeds are 1.5-4.5 $km \cdot h^{-1}$ (Wells et al. 1999). Ideally, coverage of the entire survey area should be repeated four times a year to account for seasonality, though in practicality, two times a year is likely more feasible.

Though the vast majority of marine mammal surveys to date have been conducted by use of vessels, the recent decade has seen rapid technological advancements in many fields, including aviation. The accessibility of unmanned aerial vehicles (UAV) has drastically increased, as have their capabilities, and it is possible that in the near future, UAVs may become a more efficient surveying platform than vessels. Today, UAV surveys are still bounded by limited flight time and camera functions, mainly zoom and strip width, though these features are constantly improving. As capabilities are enhanced, UAVs are expected to become front-line tools for marine research that are nearly unaffected by sea conditions, human fatigue, and observer bias.

5.2 DELPHINUS DELPHIS

Overall, it appears that 'Depth' is the best environmental parameter to explain daylight habitat preferences of *D. delphis* in the south of Israel. This result matches field observations of Israeli surveyors and researchers over the last five years.

Across the southern region of the study area, where the majority of *D. delphis* sightings occur, *T. truncatus* are also observed though in slightly deeper water depths (Figure 3B). While the environmental factors driving the depth separation of the two species in this region was not resolved by the models constructed in this study, a possible explanation may derive from differing foraging habits. Stern 2010 demonstrates the differences between trawler hauls in the south of Israel along a 20 m depth transect and a 40 m depth transect. Both transects present similar abundance and biomass of native fish species, while the 20 m transect presents elevated abundance and biomass of invasive species from the Red Sea. Upon closer inspection, the 10 most significant species from the trawler catch at both 20m and 40m were either bottom dwellers or various species of seabreams, neither of which are typical prey species for *D. delphis*, although seabream are known to be a main part of *T. truncatus'* diet. However, the trawl transects across the two depths did present differences in catch species, and since these depths do coincide with the depth separation between *D. delphis* and *T. truncatus,* this may possibly be indicative of the two dolphin species foraging on different fish species that are more commonly occurring at the respective depths.

The above speculation has been contradicted by stomach content analysis of stranded dolphins in Israel, where 4 out of 5 *D. delphis* individuals have been found to contain Balearic Eels as the most dominant species in their stomach tracks, similar to *T. truncatus* in the same region, but contradictory to typical *D. delphis* dietary preferences in other parts of the Mediterranean Sea (Brand et al., 2019). It should be noted that stomach contents of stranded dolphins may provide a misrepresentation of a species' typical dietary preferences, as they may be associated to the individual's cause of death. In the case of *D. delphis* in Israel – it is possible that feeding on Balearic Eels in the vicinity trawlers has caused the death of these individuals due to entanglement in the fishing gear. Due to the small sample size of stranded *D. delphis* stomach contents, conclusive determination of prey preferences is currently not possible for this species, and hopefully future research will be able to shed more light on this matter.

Additionally, according to personal communications with the head of the National Marine Monitoring Program, bi-annual trawls were conducted over the last seven years in the Ashdod area at depths of 20m, 40m, 60m and 80m. Results of these trawls show that sardines and anchovies (common prey species of *D. delphis*) are caught throughout the trawl transects at 20m, 40m and 60m depth. This finding further contradicts the speculation that *D. delphis'* affinity to the 20m depth strip is related to foraging, as it does not provide an advantage in relation to target prey species, which are found across a variety of depths. This observation leads to the assumption that the 20m depth is likely advantageous for other life functions.

Lastly, the depth separation between species also coincides with current trawling patterns, as trawlers in the south of Israel are not permitted to work in waters shallower than 30 m. *T. truncatus* observed in the south region often associate with working of trawlers, as was evident from the models, while *D. delphis* are only loosely associated with trawlers, and the model results showed no significance of this relationship. Furthermore, observed behavior of *D. delphis* during the majority of sightings was defined as 'traveling', 'resting' or 'socializing', and therefore strengthens the assumption that the shallow waters where these dolphins are sighted during morning hours are unrelated to foraging and serve another, currently unknown function.

An additional lesson learned from the *D. delphis* models is the difference in results when applying different statistical distributions to the model. Although the full subsets had the proportion of zeros in the data artificially reduced – the Tweedie distribution produced more reliable results than the Negative Binomial. On the other hand, the 'non-correlated' subsets appeared to produce more reliable results when applying the Negative Binomial model, although these datasets contained a larger proportion of zero values. These findings contradict the general assumptions regarding the advantages of each of these two distributions and emphasize the importance of evaluating the raw data for suitability for modeling and evaluating the model choices for suitability in regard to the data.

Lastly, although GAMs are inherently not able to describe differences between predetermined zones of presence or absence, as in the case of *D. delphis* in the north vs south of the study area, the question regarding this species limited distribution remains. Several environmental factors differ between the north and south regions of the study area, with nutrient levels presenting a key component. The largest regional source of nutrients continues to be the Nile River delta, though dammed in 1965. The High Aswan Dam has restricted the quantity and altered the seasons during which the water of the Nile River flow into the Mediterranean. This in turn has affected the regional fisheries (e.g., Sardines) and seasonal chlorophyll blooms that are associated with the output of nutrients (McCall 2008). Despite the dam, remote sensing from satellites reports higher concentrations of 'chlorophyll *a*' in the vicinity of the Nile River delta, and up to the Gaza strip that borders the southern-most end of the study area (D'Ortenzio et al., 2009; Suari et al., 2015). Although 'chlorophyll *a*' was not able to be included in the models produced by this study, it is still likely that nutrients and chlorophyll concentration are part of the defining factors, resulting in the persistence of *D. delphis* in the south of Israel.

<u>Future Research:</u>

As the surveying effort for *D. delphis* in Israel is still in its early stages, it is important to continue the data collection and re-evaluate the population size and distribution every year. However, due to the small size of this resident and isolated population, research should be focused on identifying and reducing anthropogenic risks, as loss of any individuals would be critical to the survivability and preservation of this group.

5.3 FINAL THOUGHTS

Across all maps created during this study it is evident that *T. truncatus* and *D. delphis* are present in segregated areas of the Israeli continental shelf, and furthermore, there are no recorded observations of mixed species groups or interactions between the two species.

The models only provided partial answers to this difference in distribution, showing that *D. delphis* prefers shallower depths and *T. truncatus* prefers association with trawlers, and fish farms. Additionally, sightings of *T. truncatus* occur across the entire length of Israel's coastline while *D. delphis* sightings are clustered and confined to the south region. Although the restricted distribution of *D. delphis* may be related to higher concentrations of nutrients from the Nile River delta, this speculation was not able to be confirmed by use of GAM models, mainly due to constraints in the collection of environmental data.

Lastly it should be noted that highly mobile organisms such as dolphins, often travel between different feeding grounds and breeding or nursing grounds, and therefore not all sightings are definitely indicative of areas of suitable habitat, as some sightings may occur during times of travel in "corridors" connecting preferred habitat.

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פיזנטי ש. מסמך חוות דעת בנושא: מה גודל הנזק הממוצע שגרם לענף דיג המכמורת בגלל צינור הגז התת מימי. מרץ 2006.

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Negative Binomial Distribution, Chlorophyll *a* not incuded								
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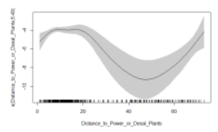	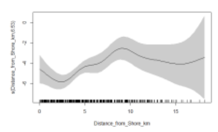	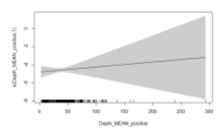	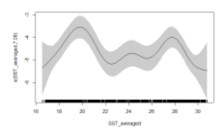	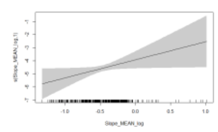		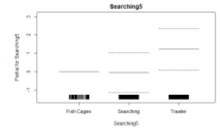	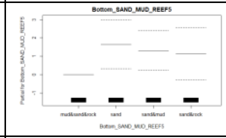	
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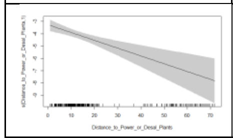
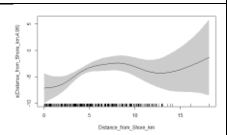
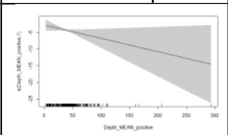
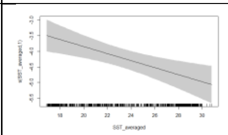
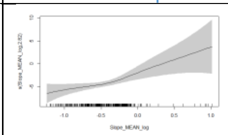
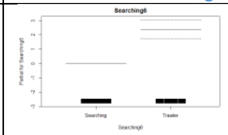
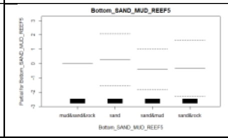
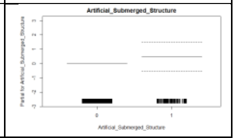
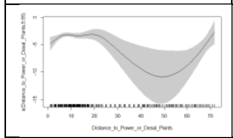
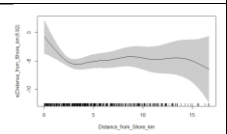
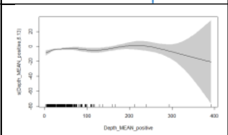
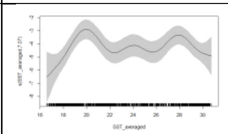
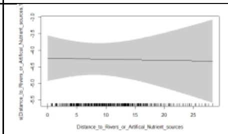
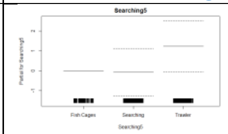
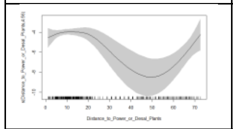
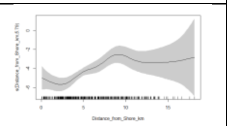
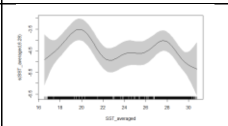
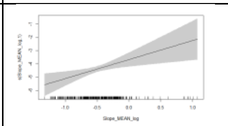
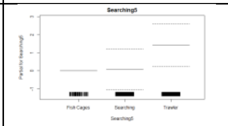
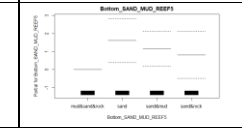
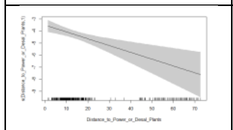
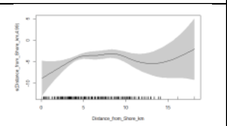
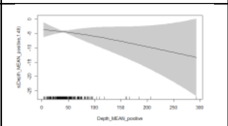
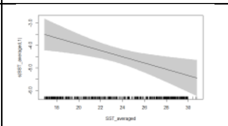
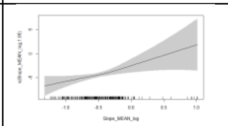
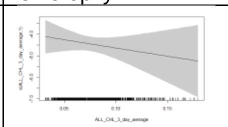
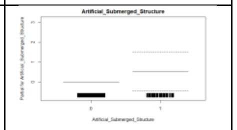
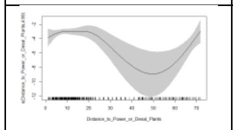
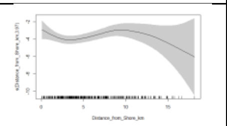
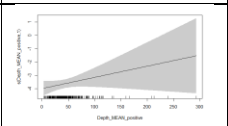
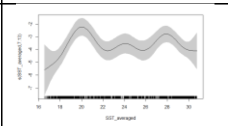
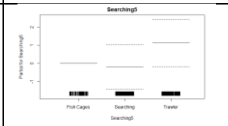
								
2010-2019 Desal	2010-2019 Shore	2010-2019 Depth	2010-2019 SST		2010-2019 Nutrients	**2010-2019 Searching**		
								
Negative Binomial Distribution, Chlorophyll *a* included in dataset								
All Years Desal	All Years Shore		All Years SST	All Years Slope		**All Years Searching**	All Years Bottom	
								
1999-2009 Desal	1999-2009 Shore	1999-2009 Depth	1999-2009 SST	1999-2009 Slope	1999-2009 Chlorophyll	1999-2009 Searching		1999-2009 Structure
								
2010-2019 Desal	2010-2019 Shore	2010-2019 Depth	2010-2019 SST			**2010-2019 Searching**		
								

אפיון התפוצה של הדולפינן המצוי והדולפין המצוי לאורך מדף היבשת של ישראל באמצעות מידול העדפות בית גידול

אורי גלילי

תקציר

לאורך חופי הים התיכון של ישראל נפוצים שני מיני דולפינים חופיים - הדולפינן המצוי (פגיע, על פי ה-IUCN) והדולפין המצוי (בסכנת הכחדה, על פי ה-IUCN). שני המינים הללו נצפים במהלך הפלגות סקר ייעודיות וגם בתצפיות מזדמנות של יורדי ים שונים, אך דגם תפוצתם שונה - הדולפינן המצוי נצפה לאורך כל חופי ישראל, ואילו הדולפין המצוי נצפה רק בדרום הארץ. בנוסף, חוקרים בישראל עוקבים אחר הדולפינן המצוי מזה 20 שנה, בעוד שרק בעשור האחרון החל הדולפין המצוי להראות נוכחות בולטת בדרום ולבסס שם אוכלוסייה מקומית.

התנאים הסביבתיים והגורמים האנתרופוגניים המשפיעים על התפוצה המרחבית של מינים אלו וקובעים את העדפות בית הגידול שלהם באיזורנו אינם ידועים, וההבנה שלהם קריטית לתכנון המרחב הימי ולמאמצי שימור. מחקר זה שואף לצמצם את פערי הידע על ידי ניתוח העדפות בית הגידול של שני מינים אלו באמצעות מודלים מסוג Generalized Additive Models המבוססים על התפוצה שנצפתה. מאחר וטורפי על כגון דולפינים הם אינדיקטורים מרכזיים לבריאות המערכות האקולוגיות בהן הם חיים, הידע שנרכש במסגרת מחקר זה עשוי לשקף את מצבם הסביבתי של המים החופיים בישראל.

במהלך מחקר זה יוצרו הערכות שפעה, מפות נוכחות ומודלי העדפות בית גידול עבור שני מיני הדולפינים. מגוון המשתנים המסבירים שנבדקו בתהליך המידול כלל: עומק קרקעית, שיפוע קרקעית, מרחק מהחוף, טמפרטורת פני הים, מרחק מתחנות כוח או מתקני התפלה, מרחק מנחלים או מקורות נוטריינטים מלאכותיים, נוכחות של מבנים מלאכותיים, סוג קרקעית ומצב החיפוש בסקר (חיפוש כללי / חיפוש בקרבת ספינות מכמורתן / חיפוש בקרבת כלובי דגים).

במהלך המחקר נמצאה נוכחות של הדולפינן המצוי בכל אזורי מדף היבשת אשר נסקרו בהפלגות המחקר בכמות מספקת. השפעה הכוללת של מין זה מוערכת בכ-15 ± 135 פרטים עם גודל קבוצה ממוצע של 4.6 ± 5 פרטים. תצפיות מאזור מפרץ חיפה וצפונה היו נדירות, אך גם מאמץ הסקירה באזור זה נמוך מאזורים אחרים. על פי תוצאות כל המודלים, לאורך שאר חלקי מדף היבשת נוכחות של הדולפינן המצוי הייתה קשורה בנוכחות ספינות מכמורתן, דבר אשר מצביע על השפעה אנתרופוגנית חזקה. כאשר בוצעה השוואה בין עונות בהן המים חמים לבין עונות בהן המים קרים, נמצא קשר בין נוכחות הדולפינינים לספינות המכמורת בתקופה שבה המים חמים, אך לא בתקופה שבה המים קרים, ממצא שעשוי להיות קשור למאזן אנרגטי או זמינות טרף. מודלים אשר נטרלו את השפעות ספינות המכמורת ניבאו כי ההסתברות הגבוהה ביותר לנוכחות דולפינינים הינה במסדרון מקביל לחוף במרחק של 6-10 ק"מ ממנו או בעומק קרקעית של 40-70 מטרים, תלוי במודל. עם זאת, לא ניתן לקבוע בוודאות אם ההעדפה כלפי אזור זה קשורה לעומק הקרקעית, המרחק מהחוף, או למשתנים אחרים ומורכבים יותר כדוגמת דגמי תפוצה של טרף או ציפייה לספינות מכמורת, אשר גם הם עשויים להיות מושפעים מהגורמים שהוזכרו לעיל.

במחקר זה נמצאה נוכחות של הדולפין המצוי בין אשדוד לאשקלון, בנוסף למספר תצפיות נקודתיות באזורים מעט צפוניים יותר, אך הגורמים אשר מגבילים את תפוצתו לכיוון צפון עדיין אינם ידועים. השפעה הכוללת של מין זה מוערכת בכ-37 פרטים עם גודל קבוצה ממוצע של 6.3 ± 16.2 פרטים. תוצאות המודלים היו מוגבלות בשל פרק הזמן הקצר בו נצפו פרטים ממין זה, בשילוב עם שטח גאוגרפי מצומצם ומספר נמוך של תצפיות באופן כולל. למרות זאת, תוצאות מודלים הראו זיקה של מין הזה לאזורים בהם עומק הקרקעית הינו כ-30 מטרים.

זהו המחקר הראשון אשר בוחן את העדפות בית הגידול של הדולפינן המצוי והדולפין המצוי לאורך חופי ישראל. תוצאות המחקר מראות השפעות אנתרופוגניות משמעותיות על אוכלוסיית הדולפינן המצוי ומעידות על כך שמין זה נמצא באיזון עדין עם פעילויות האדם באזור. תוצאות מחקר זה מחזקות את הצורך בהמשך ניטור ובשימת דגש על שיטות ציד והעדפות מזון במחקרי ההמשך.

אפיון התפוצה של הדולפינן המצוי והדולפין המצוי לאורך מדף היבשת של ישראל באמצעות מידול העדפות בית גידול

מאת: אורי גלילי
הנחיית: פרופסור דן צ'רנוב
דוקטור אביעד שיינין

עבודת גמר מחקרית (תזה) המוגשת כמילוי חלק מהדרישות
לקבלת התואר "מוסמך האוניברסיטה"

אוניברסיטת חיפה
הפקולטה למדעי הטבע
בית הספר למדעי הים על שם ליאון צ'רני
החוג לביולוגיה ימית

נובמבר 2021

אפיון התפוצה של הדולפינן המצוי והדולפין המצוי לאורך מדף היבשת של ישראל באמצעות מידול העדפות בית גידול

אורי גלילי

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